INSTRUMENTS

THE MAGAZINE OF MEASUREMENT AND CONTROL

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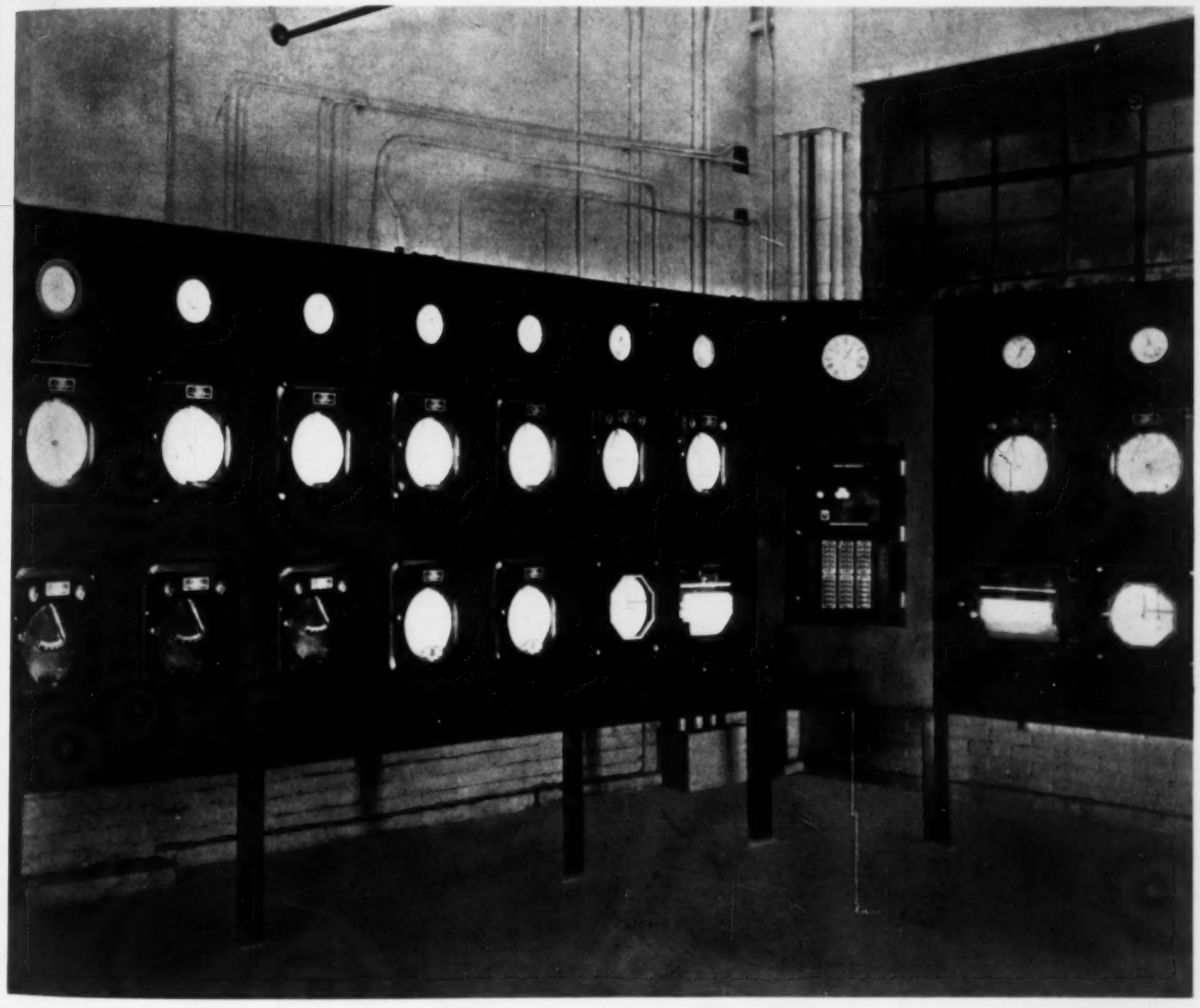

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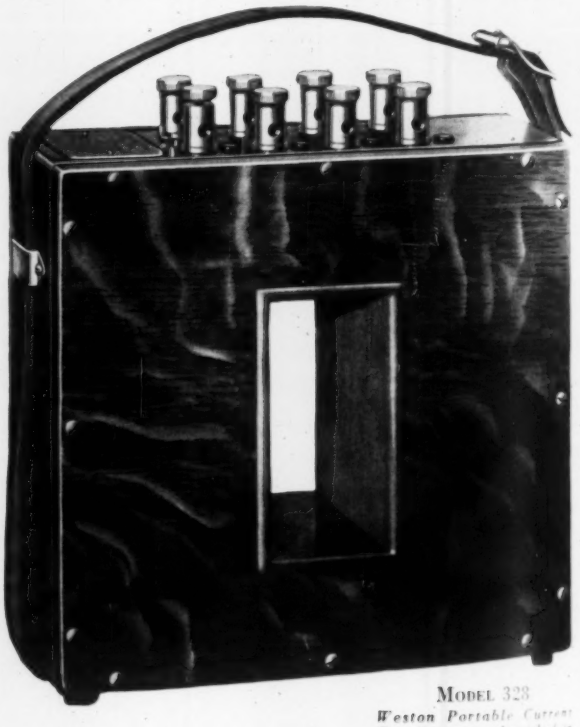

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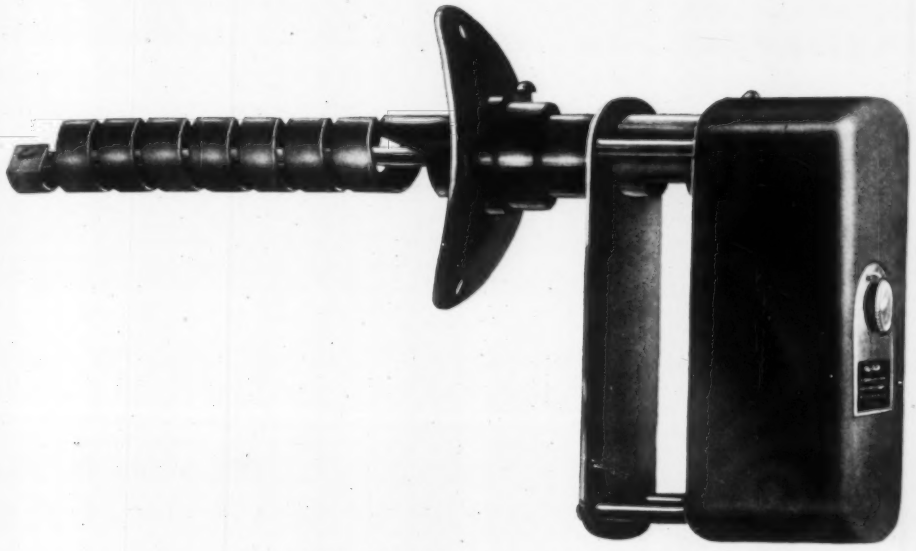

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INSTRUMENTS

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...and the superintendent added: "The Taylor System of Temperature Control has increased production, assured higher quality and saved money."

ONE after another the reports roll in. Take the one from this large Southern plant. Several years ago a Taylor System of Temperature Control was installed.

Today, the superintendent calls the system one of the most essential additions in equipment ever made for improving the uniformity of their products.

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EDITORIAL COMMENT

In This Issue

A tremendous amount of research preceded the writing of a single paragraph of C. H. Gibbons' treatise on testing machines which starts in this issue; and when he had gathered his mass of data, he then undertook a labor of love—writing and re-writing and polishing up until he produced a gem of presentation—a gem of purest ray serene that shone so bright in the setting of "Baldwin Locomotives" (where so few of our readers would see it) that once again our "print-only-exclusive articles" rule had to be broken—and once again, we believe, for your pleasure and information.

Whatever your line of work may be as an instrument *user*, you probably have said to yourself on various occasions that instrument *makers* could give out some valuable information on "how they do it." Maybe you thought them a secretive lot. They're not: they're usually too busy, however, to write about their work. E. F. Reed is busy with the Westinghouse instrument and meter Inspection Department, but he has found time to write about his work; and when you read his article you will realize that he, too, is an instrument user: he depends on inspection instruments rather than on human senses.

Which reminds us that in every instrument factory we go through, we always see many instruments in use which were bought from other firms. The men in charge could "make their own" for they know how, but—just because they *are* specialists—they realize that it doesn't pay.

This month's instalment of our industrial electrical measurement series runs to sixteen pages—but really we feel that we have hardly begun to discuss the d.c. bridge and its practical applications. Perry Borden alone could write 160 pages on this subject.

The Front Cover

You have, no doubt, been reading and hearing about the new "Duo-Sol" process, and it may have occurred to you that its success depends on close control of pressures, temperatures, flow rates and liquid levels. Correct! And our cover shows what we may call the mechanical and electrical "brains." In the center is a Brown multi-point indicating potentiometer, flanked by two Brown multi-point recording potentiometers; at the lower left are three Tagliabue indicating pressure controllers; above and next to which are seven Tagliabue pressure recorders. The three square-case instruments with small air gages in the middle row are Tagliabue pressure recorder-controllers. The octagon-bezel recorders are recognizable as made by the Republic Flow Meters Co.

"100% Automatic Inspection"

FROM time to time we are asked, "what is the most promising field of Instrumentation today?" In the inquirer's mind, of course, the question may be, "In what branch of Instrumentation am I likely, at this time, to find the best opportunities?"

On this subject one man's opinion is—one man's opinion. While we never refuse to answer, we prefer to analyze individual cases, for our opinion in *general* terms is that *all* fields of Instrumentation are "promising."

We should like to hear the question put with one word changed, thus: "What is the most promising field FOR Instrumentation today?"

To such a question we are prepared to snap a two-word answer, to shout with fanatical passion the magic words "Automatic Inspection."

Skeptics will say that this is a field where human judgment reigns supreme; that even where limit gages and comparators are used they must be handled by trained inspectors; that the most important kinds of inspection are *tests* which can never be automatized; that no robot can be built for automatically judging "quality" or passing on "properties"; that even if automatic inspection instruments have been built, they can't amount to much and that those in use are outnumbered a million to one by the "regular" types of indicators, recorders, meters and controllers—by the familiar forms of measurement and control devices, by the myriad examples of "logical" or "common sense" Instrumentation.

We are confident that our subscribers will not only refuse to join the scoffers but will discover many opportunities in this *uncultivated* field—and will appreciate the richness of the rewards in store for diligent cultivators.

Seldom was the trite expression "barely scratched" more applicable. As the skeptics say, the ratio of automatic regulators to automatic inspectors (in use) is a million to one. But while their inference is "it won't work," our conclusion—and yours—is "It Can Be Done!" As evidence we adduce the automatic inspectors and "property controls" which *have* been fully developed: Few in number, to be sure, but significant as pieces of evidence.

One example: Just four years ago—in the November 1930 issue—sermonizing on the scientific instrument of today being the plant instrument of tomorrow, and discussing the vanishing line between laboratory testing devices and industrial production instruments, we wrote

> Today there are no industrial instruments pertaining to hardness. Tomorrow one may be invented and in a few years we may witness the production of bar stock whose hardness is controlled not in the laboratory but automatically during production.

Now, in 1934, this very thing is being done in a razor blade factory: as the high-carbon strip passes out of a continuous furnace, its hardness is measured by an automatic inspector that never tires, never stops for a drink, never stares at the girls but incessantly carries out the orders which the human inspector gives it from time to time. This robot not only inspects every inch of the fast-moving strip but it controls the furnace with superhuman alertness so that every inch of strip has just the right hardness.

This, of course, is such a marvel of Instrumentation that cynics may dismiss it as a "curiosity," but the fact remains that the gap between (in this case) magnetic *testing* in the laboratory and magnetic *inspection* in the plant has been bridged. Of greater significance is that the problem of rejects and seconds has thereby been solved: instead of subsequent human "guesstimation" as to which lots of blades are good and which are bad with respect to the property known as "hardness," the robot inspector sees to it that the continuous furnace turns out nothing but good strip.

Our enthusiasm, however, is not based on curiosities but on the increasing number of successful automatic inspectors already on the market. Look over our New Instruments Section beginning with the 1931 or 1932 issues and observe the trend for yourself.

M. F. Behar

Materials Testing Machines

An Account of Their Development, with Special Reference to the Tension-Compression-Transverse Group

By C. H. GIBBONS*

THE earliest materials testing machines were devices of the civil engineer and of the physicist. Their use was intimately associated with the construction of bridges, harbor works and buildings. Later the mechanical engineer found them indispensable as the invention of the steam engine permitted the concentration of greater power on individual mechanisms which, in turn, made vitally necessary a knowledge of the strength of materials in order that machines designed for a given function should contain material of proper kind and of sufficient quantity to prevent failure as increasingly large power was applied. Thus it became necessary for machines to test the materials of other machines and from such stimuli grew the industry of materials testing machine manufacture.

Research reveals Galileo (1564-1642) as the first systematic investigator of the strength of materials (Fig. 1a). As a result of tests on tenacity[1] (about 1638), he estimated that a rod of copper, if "4800 arms" in length and suspended from one end, would fail of its own weight. He assumed that beams in bending were stressed in tension over the whole of the section and made calculations of strength on this basis. About forty years later (1680) Mariotte perceived that part of the section was in compression.[2] In 1776, Coulomb located the neutral axis for simple sections and in 1824 Navier determined the location for all sections.[3]

*Baldwin-Southwark Corp., Philadelphia, Pa.

[1]Fontenelle, Histoire de l'Académie Royale des Sciences, 1702, page 121.

[2]Mariotte, Traité du Mouvement des Eaux, 1680.
Liebnitz, Memoir in the Leipsic Acts, 1684.
Varignon, Mémoires de l'Académie Royale des Sciences, 1702.

[3]W. C. Unwin, *Engineering* (London), Vol. 92, page 643.

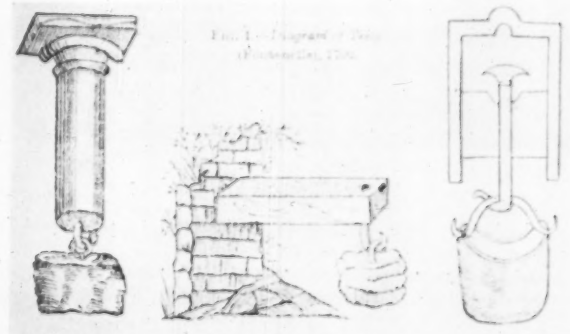


Fig. 2.—*Test-pieces used by Musschenbroek, 1729*

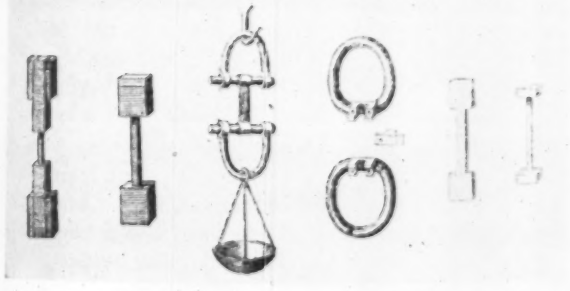


Fig. 1a. Galileo's test methods, 1638.
Fig. 1b. Musschenbroek's test specimens as used on the machine shown in Fig. 2.

Before 1729 Pieter van Musschenbrock, Professor at the University of Leyden, had made numerous tests and seems to have been the first investigator to use methods of precision.[4] (Fig. 2) His investigations covered tension, bending and compression in long columns, but on a small scale only, his wood tensile specimens being 1 5″ square, and his metal tensile specimens being about 1 10″ in diameter.[5] (Fig. 1b)

But France and England seem to share nearly equally in the early development of practical materials testing machines. The knowledge these machines offered the designer and the builder became imperatively necessary as the demands of an expanding civilization required larger bridges of longer spans and more imposing buildings of greater dimensions.

In France this stimulus came, at least in part, from the fact that the supervision of bridge building was a government function. In 1715 the Department of Bridges

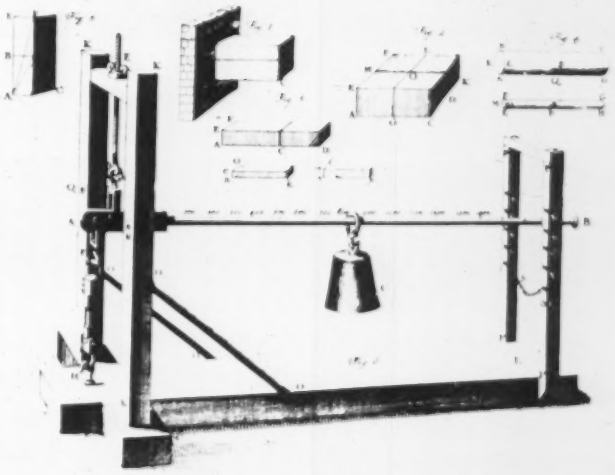


Fig. 2. Musschenbroek's testing machine, 1729.

and Roads was created, and in 1747 a school was organized in connection therewith to teach young men the principles of design and construction. This school was reorganized in 1760 as the Ecole des Ponts et Chaussées by Jean-Rodolphe Perronet (1708-1794), the Dean of French engineers.

Perronet, in 1768,[6] was building to his own design the masonry arch bridge across the Seine at Neuilly-sur-Seine (1768-1774). This bridge has five elliptical arch spans of 128 feet each and a rise of 32 feet. It is considered one of the best examples of Perronet's genius as an engineer.[7]

Because pertinent questions as to the capacity of his materials to sustain loads could not be answered with

[4]Musschenbroek, Introductio ad Cohaerentiam, Corporum Firmorum, 1729.
Peter Barlow, The Strength of Materials, 1867, page 3.

[5]W. C. Unwin, *Proceedings Institution Mechanical Engineers*, Oct. 1918.

[6]Lesage, *Second Recueil de Mémoires des Ponts et Caussées*, 1810, says in 1758.

[7]A fine line drawing of this bridge may be found in Gauthey's "Ponts," 1809 (Navier).

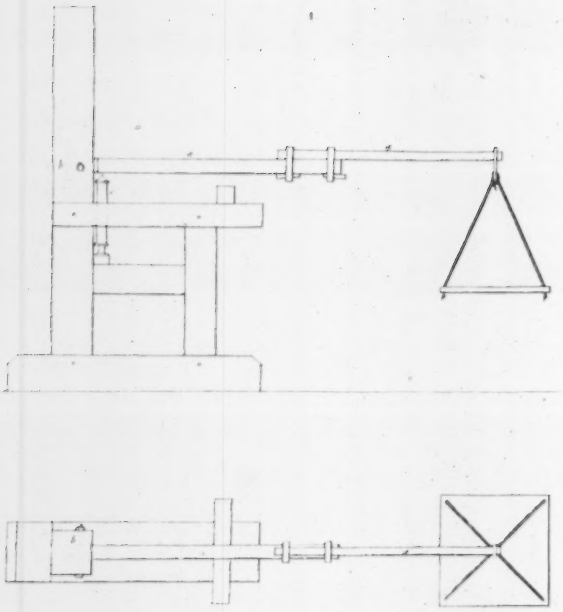


Fig. 3. M. Gauthey's testing machine, about 1768.

certainty, he built the first comparatively large universal testing machine to answer them. It was of about 18 tons capacity and was, doubtless, the largest and most powerful which had been built up to that date.[3, 8, 9]

About the same time M. Gauthey (1732-1806), Inspector General of the Department of Bridges and Roads, built a testing machine which, in its essential principles, was the same as that of Perronet. (Fig. 3.)[10, 11] Because of an argument which he had in regard to the validity of the design of certain parts of the Church of Ste. Géneviève, he built this compression testing machine in which he tested the stone used in construction, and decided that of two grades of stone one would support a column of itself of a height of 537 meters, while the other would support a 1,300-meter column of itself.[10]

A little later, M. Soufflot (1713-1781), engaged in the construction of the same edifice, built another testing machine, "toute en fer,"[10] which he, in association with Perronet and Rondelet, used in making a great number of tests.[10] (Fig. 4.)

Perronet built for the Ecole des Ponts et Chaussées a universal testing machine (Fig. 5), but whether or not this is the same one as that mentioned previously as being of 18 (18,650 kg.) tons capacity and having been used in the testing of the materials of the bridge at Neuilly-sur-Seine, has not been established. He continued, however, to build bridges and, doubtless, to test their materials, throughout all the disturbed political and social conditions in France which culminated in the French Revolution, and until his death in 1794.

[8]Lesage. *Second Recueil de Mémoires des Ponts et Chaussées*, 1810, page 167.

[9]Perronet, too, noted the effects of scratches and of notches on tensile test specimens and the rise of temperature of the specimen at failure. See Thos. Tredgold, *Philosophical Magazine*, Vol. 50, Dec. 1817, page 413.

[10]Rondelet. Traité de l'Art de Batir, 6th edition, 1830.

[11]Navier. Oeuvres de Gauthey, 1809, *Journal de Physique de l'Abbé Rozier*, Nov. 1774.

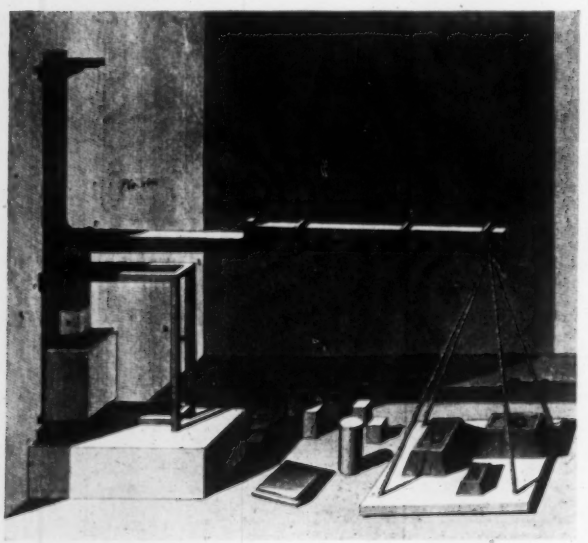


Fig. 4. M. Soufflet's testing machine, about 1775.

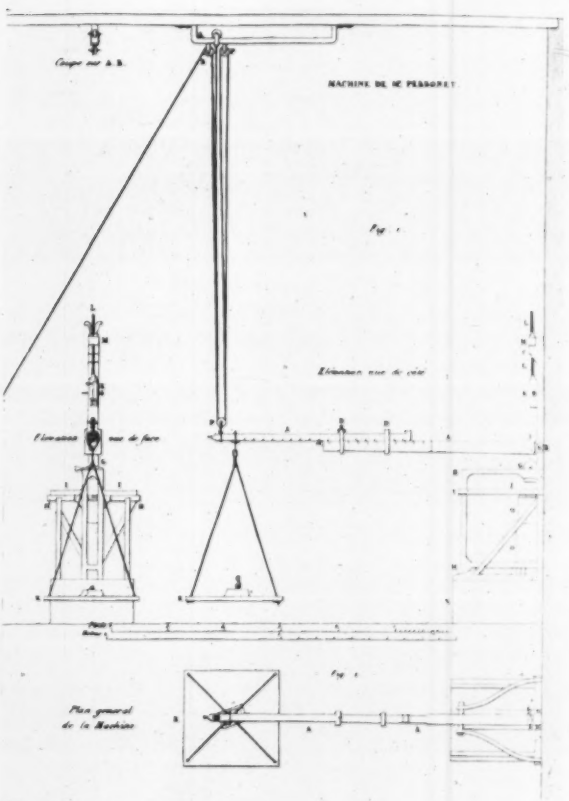


Fig. 5. M. Perronet's testing machine, about 1770.

Jean-Baptiste Rondelet (1743-1829), mentioned previously as an associate of Soufflot and Perronet, on the death of the former (1781), accepted responsibility for the construction of the Church of Ste. Géneviève (The Pantheon). He had coöperated on many tests with the machine of Perronet at "l'Ecole," and was well aware that the friction in the fulcrum pin of the great lever of this machine, and in that of Gauthey, had invalidated results to an unknown degree.[10] He, therefore, in 1787 built a testing machine of the lever type, having knife edges and with a screw arrangement for counteracting strain (Figs. 6 and 7).[3, 10] This machine was capable of compression testing only, and on it were tested timber and stone to be used in the construction of the edifice. The capacity of this machine is not stated, but it is prob-

able that it was less than 35,000 lbs.[12] It is believed to have been the first testing machine to incorporate all the essentials of current screw-power, lever-and-poise testing machines.

Lamblardie (1747-1797),[13] soon after, constructed a testing machine for the Port of Havre of 100 tons (224,000 lbs.) capacity and P. S. Girard (1765-1836) used it to determine for the first time,[3, 5, 14] on a large scale, the elasticity of materials. Girard, in his "Traité Analytique de la Résistance des Solides," 1798, pictures two crude testing machines, adaptable for compression testing only, and apparently used only for testing of long columns of wood. It does not seem probable that either of these machines had a capacity of as much as 100 tons.[15]

In England another material for bridge construction was engaging the attention of engineers. This was cast iron. While the use of cast iron for bridges goes back into medieval times—some bridges in China and in

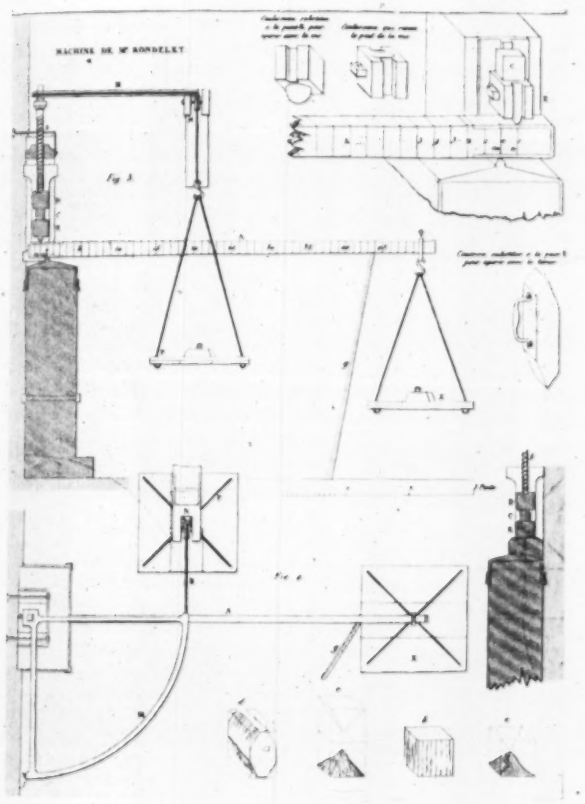


Fig. 6. M. Rondelet's testing machine, about 1787.

Japan, as early as this, having cast iron chains for suspension cables—the earliest attempted use in Europe was in 1755 at Lyons, France, and this attempt was unsuccessful. From 1773 to 1779, however, in England was built the first cast iron bridge in Europe, and the first in the world to be composed entirely of cast iron.

This bridge was over the Severn at Coalbrookdale between Medley and Brosely, and was built by John

[12]The original account in Traité de l'Art de Batir of the genius of Rondelet in his efforts to eliminate all friction from the machine is unusually interesting. The student interested in the development of such machines will find it worthy of his time.

[13]First Director "Ecole Centrale de Travaux Publics," later "Ecole Polytechnique" (1795).

[14]P. S. Girard. Traité Analytique de la Résistance des Solides, 1798.

[15]Although it is definitely stated in the preface to "Traité Analytique, etc.," that the capacity was "cent mille kilogrammes." The tabulations, however, show no loads beyond 62,554 kg. (about 140,000 lbs.).

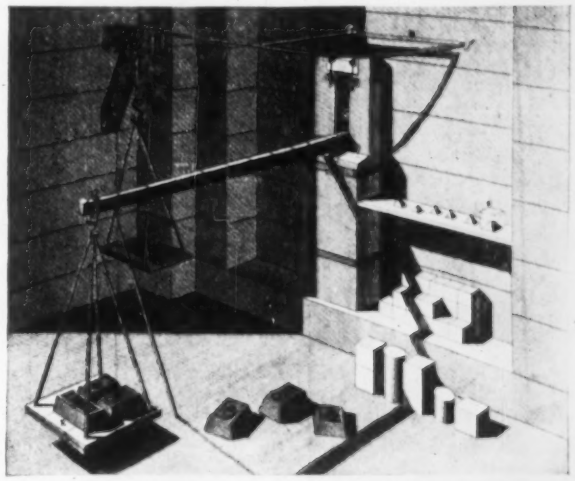


Fig. 7. M. Rondelet's testing machine of 1787.

Wilkinson and Abraham Darby to the designs of Thomas Farnolls Pritchard, an architect of Eyton Turret. It was in service still and in good condition 125 years later.[16]

While there is no evidence of a testing machine of any nature having been used in proving the materials of this bridge, it marked the beginning of a method of bridge and building[17] construction which shortly required such machines, and several were built by famous British engineers of the early years of the nineteenth century, among them being Rennie, Telford, Barlow, Brown and Tredgold.[18]

Between 1775 and about 1845 numerous bridges of cast iron were built in England. Among these was the Southwark Bridge over the Thames in London, which was built by the elder John Rennie (1761-1821). This was the largest cast iron bridge ever built and contained nearly 6,000 tons of metal. About 1840 Robert Stephen-

[16]Tyrrell. History of Bridge Engineering, 1911. A fine line cut of this bridge may be found in Rondelet, Traité de l'Art de Batir, Vol. 3, part 2. Navier, Ponts Suspendus, 1830, page 3.

[17]The earliest cast iron beams in buildings were used by Messrs. Boulton and Watt in building a cotton mill in Manchester (England) in 1800. Encyclopedia Britannica, 8th edition, "Bridges."

[18]A fine tabulation of early tests with credit in each case to the experimenter may be found in *Philosophical Magazine*, Vol. 50, Dec. 1817, page 415. This tabulation contains results on tests of iron, steel, copper, gold, silver, platinum, bismuth, alloys, wood, stone and miscellaneous such as "horn of an ox," the latter credited to Musschenbroek.

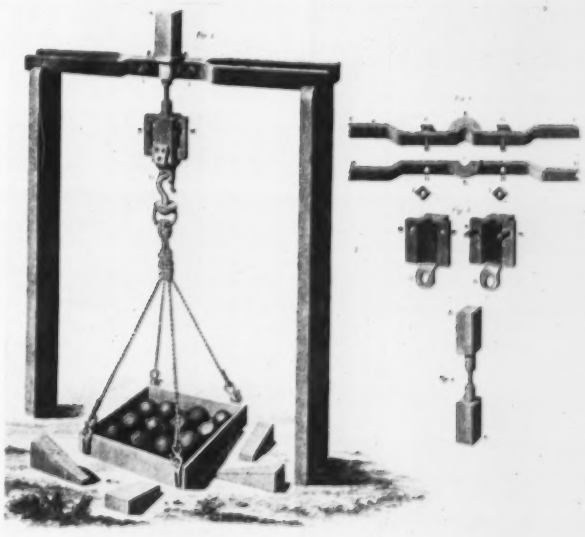


Fig. 8. The testing machine of Peter Barlow, 1817.

son (1803-1859), son of George Stephenson (1781-1848), inventor of the locomotive, designed two bridges for service over Menai Straits; one of cast iron construction, and one of tubular construction and of wrought iron.[19] Before proceeding with construction he employed Wm. Fairbairn, Eaton Hodgkinson and Edwin Clark to make elaborate tests extending from 1840 to 1846 and, as a result of which, he chose the more ductile material in place of cast iron. While other cast iron bridges were built, these tests mark the end of the era of cast iron bridges. Henry Bessemer's (1813-1898) invention of the Bessemer process of steel making (1862), in turn, was destined to cause the displacement of wrought iron for this purpose, so that by 1895 wrought iron shapes were no longer rolled.[20]

One of the earliest of the English testing machines was that at Brunton's Patent Chain and Cable Manufactory. In 1813, on the introduction of chain cable for ships' anchor suspension,[21] a Mr. Fuller designed a chain cable testing machine having an hydraulic cylinder (known as a Bramah Press, patented by Joseph Bramah in 1795)[22] and no weighing device, the load being estimated from a manometer or "valve"[23] reading of the unit pressure in the cylinder, multiplied by the area of the ram.[24] This machine was later (1814) used by Thomas Telford (1757-1834) in his materials tests[25] at the time he proposed the 1,000-foot suspension span over the Mersey at Runcorn near Liverpool.

About the same time[26] Captain Sam Brown (1776-1852), British Navy, of Mill Wall, Poplar, London, constructed another testing machine, in which gearing was used for load production and for strain compensation, and a lever was used for weighing the load.[5, 24] Its primary purpose was the testing of cast iron chain cables.

In 1816 there was constructed in the plant of Brown, Lennox & Co., Chain and Cable Works, Pontypridd, South Wales, a horizontal testing machine, whose capacity is not known but whose lever ratio was 100 to 1. Load was applied and strain compensated by means of gearing, and the final link between the specimen and the gearing was a flat link chain which was wrapped around one of the shafts of the gear train. Loads were weighed by the lever system. This machine was in use, still, in 1906.[27]

Prior to 1817, Peter Barlow (1776-1862), Professor of Mathematics at Woolwich Academy, had carried out many tests[25] on timber "at the Dock Yard and at the Arsenal," Woolwich, London.[3] His testing machine is shown in Fig. 8. The ends of the wood specimens were $1\frac{1}{2}$" square and $31\frac{1}{2}$" long. Between these ends was a 5" length turned to $\frac{3}{4}$" diameter near the square ends and to 1.3 to $1\frac{1}{4}$" diameter between. Because they had no means of accurate measurement of this diameter, a fine silk thread was wound ten times around the specimen, removed and measured and the diameter found by calculation. The box or "scale" was wedged up until the majority of the weights had been placed. The wedges were then carefully removed and smaller weights added until failure of the specimen. The weights were 10-, 8- and $5\frac{1}{2}$" diameter "shells" loaded with musket balls to 100, 50 and 15 lbs. respectively. A few weights of 7, 4, 2 lbs., etc., were provided for final "make-up." In addition, means (not shown) were provided to prevent the introduction of bending stress into the specimen by the swaying or vibration of the scale.[18, 25]

[To be continued]

[19] The first wrought iron bridge is supposed to have been designed by George Stephenson (1823). It was over the Gaundless River near West Auckland, England. See Tyrrell, History of Bridge Engineering, 1911.

[20] First wrought iron shapes were rolled by Henry Cort (1740-1800), of Gosport (near Portsmouth) England, in 1783.

[21] Wicksteed, *Engineering* (London), Vol. LXXVIII, 1909, pages 211, 305, 322.

[22] The Branch Press Model in Kensington Museum made in 1796 had a lever system for measuring the load exerted by the press. See *The Engineer* (London), Vol. 18, Oct. 28, 1864, page 269.

[23] There is no evidence discoverable of the exact nature of the pressure measuring equipment. The probabilities, however, favor the use of the "valve" which persists today as the weight-loaded or spring-loaded safety valve. This device had an adjustment which was varied until leakage began. Pressure was estimated from that point of the adjustment and load estimated from the pressure. See de Pombour, "A practical treatise on locomotive engines," etc., 1840 edition. Or it may have been a ram in a cylinder of the type shown in Fig. 19 with a weighted lever to supply the necessary reaction. Such a weighting device was used on a testing machine at Lloyds, New Road, Poplar, London, 1863. See *The Engineer*, Vol. XV, May 8, 1863, page 265.

[24] Navier, Mémoire sur les Ponts Suspendus, 1830, pages 244, 246.

[25] Peter Barlow, A treatise on the strength of timber, cast and malleable iron, etc. London, 1851.

[26] Wicksteed, *Proceedings Institution Mechanical Engineers* — says (1906) "in 1812" and Peter Barlow, A treatise on the strength of timber, etc., 1837, says that Capt. Brown invented "iron cables" and built the first machine for testing them.

[27] Wicksteed, *Proceedings Institution of Mechanical Engineers*, 1906, pages 543 *et seq.*

Discussion on "Filing Ideas" Article

To the Editor:

I have been reading Mr. Trofimov's article on "Filing Technical Ideas" in the June issue of *Instruments*, and have been impressed by the general utility of his ideas. Physicists in the last few years have been finding it fruitful to analyze their concepts from the point of view of the operations involved in arriving at these concepts (see, for instance, Bridgman's book, "The Logic of Modern Physics"). Mr. Trofimov shows us that it also is useful to classify technical problems from the operational point of view. There are a few gaps in his classification (for instance, would he classify problems concerned primarily with light or other radiation under Force or Substance?) but this is, of course, a minor criticism. The general idea of the operational classification of ideas is a sound one, and should be useful in pure as well as in applied science.

The article under discussion deals with the classification of articles, *i.e.*, problems already solved; but I gather from your editorial comment that Mr. Trofimov has ideas about how *unsolved* problems can be classified in a manner which will aid in their solution. I should be interested to read an article on this subject.

Massachusetts Institute of Technology
September 1, 1934

PHILIP M. MORSE
Associate Professor of Physics

To the Editor:

Professor Morse's questions are good. He asks two: (1) Should the problems concerned with radiation be classified under Force or Substance? (2) How can unsolved problems be classified for reference to the File of Technical Ideas?

The answer to the first question is that problems on radiation must be classified under Force. According to the electromagnetic theory, energy is radiated whenever an electric charge is accelerated. Force is measured by acceleration, hence radiation problems are Force problems. From the point of view of the quantum theory, radiation problems are also Force problems, because Planck's constant h is measured by erg-seconds, or dyne-centimeter-seconds, where the dyne is a force. The radiation problems must be classified under *F-Eo* (Force-electronic).

The answer to the second question may be derived from the following: A knowledge of the solution is not necessary to determine whether a problem is an *F* or *S* problem; neither is it necessary to determine the kind of force and the state of substance. Thus, you would have two first letters, for instance, in radiation problems, *F* and *Eo*. The unsolved problem also gives the prevailing condition, which is really the cause of the problem. The recognition of the kind of prevailing condition will furnish the third letter, say *S*. With these three letters *F, Eo, S*, you will go into your file and look over the four groups—*Ql, Qu, S, T, C*—of filed articles describing how similar problems were solved. It is assumed that these articles may suggest the solution for your problem.

Cleveland, Ohio
September 21, 1934

L. A. TROFIMOV

R. Y. Ferner, president of the Washington (D.C.) company bearing his name, died in New York City on October 7.

Inspection Problems in the Manufacture of Fine Mechanisms

By E. F. REED*

INSPECTION problems enter into every line of industry, regardless of the size of the plant or the article manufactured. These problems nearly always call for decisions and it is in this judicial capacity that the inspection department must function. So much is at stake nowadays that it is necessary to use methods that are practically fool-proof, leaving nearly nothing to guesswork. Recent developments in various fields have created a demand for manufactured articles capable of giving service that was neither expected nor required before the advent of the present scientific era. Every minute in the work-day of a modern plant, problems arise demanding the attention of one able to decide whether a product is marketable or not. In the course of manufacturing modern mechanisms and electrical devices certain irregularities arise at times which might affect the performance or appearance of the product, and then inspection enters into the picture as the ultimate deciding factor.

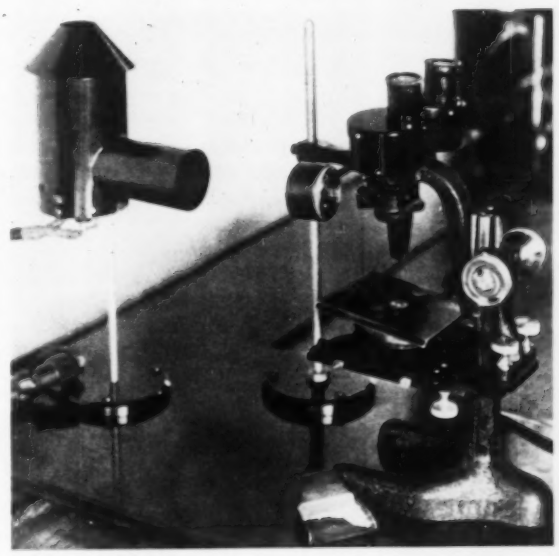


Fig. 1. Microscope set up for jewel inspection.

Poor inspection of manufactured articles is one of the most direct causes of decreased sales in any concern, to say nothing of low efficiency as a contributory factor to increased costs. No longer can the inspector depend entirely on his naked eye or other senses the Creator endowed us all with. Scientific means must be developed. They have been developed, and some of them have produced startling results in bringing to light irregularities not perceptible under old-fashioned methods. Let us follow in sequence some of the many and varied modern inspection operations from raw materials to finished products.

Raw materials received into a plant must be closely checked to make sure that they measure up to standards set in purchase specifications. Sometimes it is necessary to use a substitute, or material is secured from a different supplier, in which cases of course complete checking is necessary whether it be a steel bar, a micarta strip or a copper wire reel. The determining factor in this important part of inspection work is to see that the structure of all raw materials is of such character that performance or quality of the finished product will not be impaired by some weakness of the materials used in its construction. These qualities are determined by checking the raw material for hardness, variation in dimensions, physical properties, chemical properties, conductivity, finish and (in some cases) for color. Copper bars and wire, to cite obvious examples, must pass a specified conductivity test before being approved for use in the manufacture of indicating instruments or watthour meter parts.

Probably the best illustrations of raw material inspection, however, are found in connection with meter and instrument jewels and bearings—which are required to be "perfect" in order to raise the "merit factor" recently discussed by R. W. Carson in this magazine† and otherwise to make possible the performance demanded by users nowadays. Take for example the small steel balls used for bearings in watt-hour meters; and the fine sapphire jewels used in many types of instruments. The old fashioned method was to inspect them by feeling the surface with a steel needle to detect cracks or other flaws. It was soon learned that the sense of touch could not be depended upon at all times in segregating good jewels from defective ones with the human element and its differences in moods entering into the inspection: The best inspector was liable to be influenced by the lot undergoing inspection, to pass or reject not in accordance with fixed standards but in accordance with a more or less fixed percentage of the lot. Thus, if the jewels in one lot happened to have a greater amount of flaws or slight surface cracks than normal, the inspector was liable to pass too many of them; and if the next lot was exceptionally good in structure, the inspector was liable to reject the usual proportion of the lot. The same was true of naked-eye and tactual inspection of steel balls. Such guesswork inspection too often resulted in "judging quality by percentage of the lot."

Instead of depending upon the naked eye and upon sense of touch in this work, the aid of science has been enlisted and powerful microscopes (see Fig. 1) are now employed in exploring jewel surfaces as well as the surfaces of small steel ball bearings. These microscopes reveal flaws and cracks that would otherwise not be detected. Furthermore, in the case of the small steel balls, surface inspection is by no means all; they must pass other instrumental tests, among which is ability to withstand without permanent deformation a given pressure applied by two steel plates.

Another recent scientific development is inspection by optical projection. Gears and pinions used in meter registers, and instrument pivots, must be subjected to a visual inspection and the old method was to view them

*Newark Works, Westinghouse Elec. & Mfg. Co.

†Carson, Merit Factor for Measuring Serviceability of Electrical Indicating Instruments, *Instruments*, Vol. 7, Oct. 1934, pages 203-204.

with an ordinary jeweler's loupe or magnifying glass. Now all gears and pinions are inspected for tooth formation and eccentricity, and steel pivots are inspected for radius, by means of projectors (Fig. 2) having a magnification of 100 or 200.

The Feeder Sections of a manufacturing plant present another interesting and varied side of inspection work. In these sections products coming from punch presses, screw machines, boring, milling, tapping, planing and many other various types of machines must be closely watched for any irregularities in machine operation. Such details as the correct cutting and threading of screws, shaping, bending, piercing and drilling of various metal punchings and molded parts used in the construction of watthour meters, portable and switchboard indicating and recording instruments must come under close scrutiny of the inspector not alone for the purpose of detecting an inferior quality of work but to keep under control the tools and dies used in these many different machines as they very often become worn from continuous use.

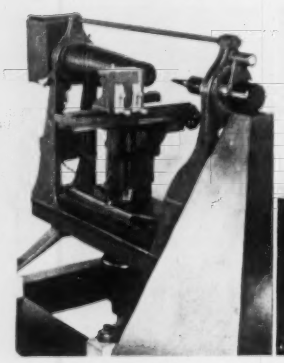


Fig. 2. Projector

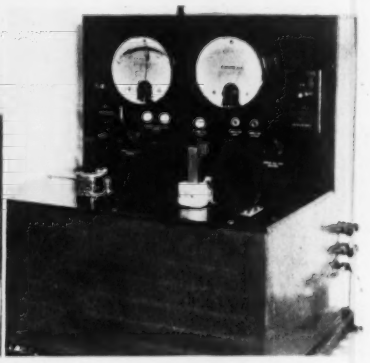


Fig. 3. Short-circuit tester

Products undergoing plating, dipping or finishing processes are likewise controlled by inspection. Certain metal parts require gold plating, some nickel plating and others perhaps a dull black lacquer finish. These parts must pass under the trained eye of the inspector so that any variances in these processes will be detected. In some instances the plating bath might not be correct, or the material itself probably was not given sufficient surface cleaning to insure a good plating job, all of which comes within the province of the inspector in his duties of guarding the quality of the product.

Coil winding presents many difficult problems to the inspector in properly controlling wire so as to reduce the possibility of "shorted" or open-circuited windings. This is accomplished by applying a dielectric test to a sample piece of wire while under tension. The wire under test must withstand a certain voltage depending upon its size, without becoming punctured. Not only does the inspection division function in the operation of the many testing devices used in this class of work such as ohmmeters, short circuit testing machines and insulation testing devices, but it has contributed in many ways to the refinement and perfection of these many intricate machines. This shows the need for versatility in this unusual field of activity as well as for the ability to supervise the making of many various sized and shaped coils, their proper insulation and the assembly of them on iron such as in the building of electro-magnets.

The final assembly of the product involves many important details which must be controlled by the inspection division. In this branch of manufacturing, detail is essential as often the finished product must be checked against blue prints and this often necessitates the use of special measuring tools such as gages, micrometers, calipers, dividers and precision scales; and adds to the intricacies of the inspector's job—to say nothing of the responsibility involved in passing the product on with the approval of being made according to specifications. Here, as in other lines of manufacturing, many difficult problems arise, one of the most troublesome being that of parts not fitting properly, which makes it impossible to complete the assembly of the product. When this occurs, inspection plays an important part in determining the reason for these difficulties. This often requires the dismantling of the instrument or meter and checking each individual part against the drawing. It sometimes requires a great amount of untiring effort in bringing to light irregularities which might appear to be negligible yet interfere with parts fitting properly. These might be in the nature of an incorrectly located hole, a screw not made to dimensions or some part not machined correctly, or even—in some instances—an error might have occurred during the tracing of a drawing. Yet inspectors must be capable of laying their finger on these discrepancies in the pursuit of their duties.

Small hand tools used in the various assembly departments must be periodically examined by the inspector for possible deformation or wear such as might occur from continuous use and results in the manufacture of an inferior part. These tools are subjected to a visual inspection at frequent intervals and are returned to the tool making department if they show any sign of wear.

Tool inspection is a vital point in the realm of inspection duties and demands the closest surveillance on the part of the inspector. These essential parts of any manufacturing enterprise must be carefully checked before being passed on for use in the manufacture of various parts. New tools and dies are checked against a tool sketch for dimensions before being sent to the feeder sections for use in various machines and then the first piece made from this new tool or die is sent to the tool inspector for examination in a projector against an enlarged perfect sketch before production is permitted to proceed. A close application of mechanical methods is required in this important branch of inspection because the parts that go to make up the finished product cannot measure up to standards if tools are not correct in detail. A sound knowledge of the fundamental principles of mechanics must form the background in the art of tool inspection as here it is necessary to detect any variations in the finished tool or tolerances that were possibly not considered in the design of the die or tool.

The significant fact ever present is the responsibility connected with the approval of tools that will be used in the making or shaping of parts that must result in a perfect finished product. Truly this might be considered the backbone of the various methods entering into the manufacture and complete assembly as would be applied in almost any line of industry.

With all these considerations we might naturally be inclined to inquire why all these precautions must be taken in the manufacture of these various parts. Some tangible reason must predominate for requiring this specialized work of supervising the product on its journey through a plant, and no better reason could be presented than the desire to incorporate the finest of quality in the finished product when it is ready for the open market. No better selling point can be offered than high quality, and this plus performance means a representation which reflects the efforts and controlling influence of inspection.

BRIDGES
And Their Applications*

By PERRY A. BORDEN† and M. F. BEHAR**

1. Bridge Circuits

Although both the potentiometer and the bridge employ the balance principle and have much else in common, they differ radically in the manner of balancing: In the potentiometer a balance is effected between the electromotive force to be measured and a measurable portion of the potential gradient along a conductor; but in the bridge a balance is obtained between *equipotential* points in *two* circuits generally connected to *one* common source of electromotive force. In the bridge, balance indicates that the relative resistance values of the subdivisions of the circuits fulfill certain conditions. These will be discussed below.

The bridge circuit was first applied in 1843 by Sir Charles Wheatstone to the comparison of resistances and hence this application is universally called the Wheatstone bridge.

No doubt, the title "bridge" has already called to the reader's mind the familiar diamond-shaped diagram, Fig. 39-1. This, however, is but one of three distinct concepts of the bridge circuit. To think of it as "the whole story" is to handicap one's self mentally. Fig. 39-1 represents the concept of the bridge circuit as four resistors forming a closed rectangle, having two opposite points connected to a source of voltage and the other two to a galvanometer.

[The notation on Fig. 39-1 differs from the usual R_1 R_2 R_3 R_4 of most texts, but it agrees with the nearly universal usage of the men who use bridges in their daily work, the A and B arms being commonly known as the *ratio arms*, R designating the adjustable resistor and X representing the resistance to be measured.]

Fig. 39-1

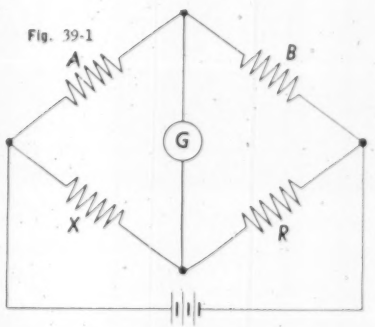
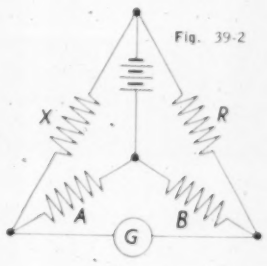


Fig. 39-2



A second concept of the Wheatstone bridge circuit pictures it as a closed network having six branches, related in the manner of the edges of a triangular pyramid, two non-adjacent branches including a source of electromotive force and a galvanometer respectively, and the remaining four arms having definite resistance values. This theoretical—but mentally useful—concept is represented in Fig. 39-2.

Thirdly, the bridge circuit may be considered as two subdivided resistors in parallel, supplied from a common source of potential and having a galvanometer connected between the points of subdivision, as shown in Fig. 39-3.

No matter how we picture the bridge circuit, however, one essential condition is that in order for both galvanometer terminals g, g to be at the same potential, each of their points of contact (c and d) with the circuit must be at an *equal voltage-distance* from either of the supply terminals e and f. Since potential drop in any conductor from which no current is diverted is directly proportional to resistance; and since the over-all voltage on the two parallel circuits is the same, the ratio of resistances of the subdivided portions of one

*Eleventh chapter (XXXIX) of Part Seven (Handbook of Industrial Electrical Measurements and Control) of Béhar's *Manual of Instrumentation*. See editorial announcement of this series on page A of November 1933 *Instruments*. A complete chapter of this new handbook will be published in each issue of *Instruments* throughout 1934 and 1935. Each chapter is subjected to a final revision, and then set in type, shortly before its appearance in this serial form, in order to assure that the subject matter is thoroughly up-to-date. This new book is not published serially in any other periodical. Entire contents copyright. To be issued in book form on or about Jan. 1, 1936.

†Member A.I.E.E. **Editor, *Instruments*

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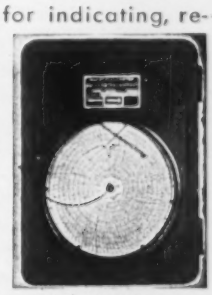

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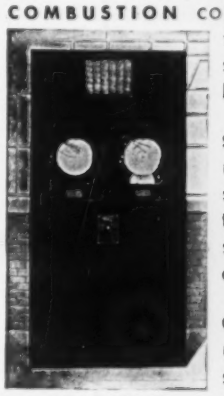

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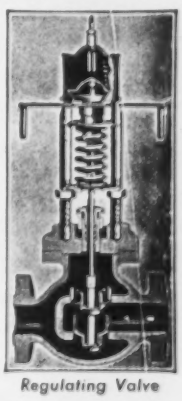

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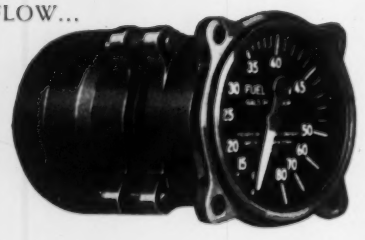

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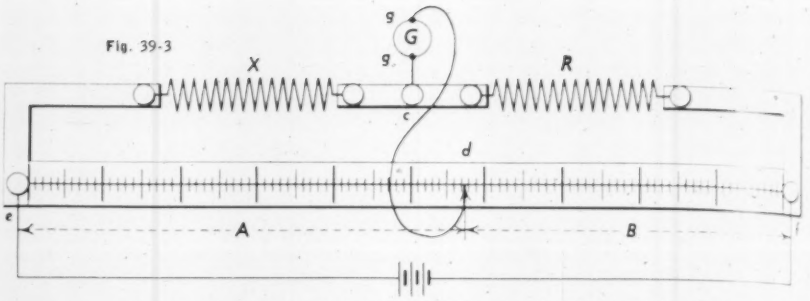
Fig. 39-3



circuit must be equal to that of the other. Thus in the form of bridge network shown in Fig. 39-1 or -2, in order for a condition of balance to exist it is necessary that the resistance values bear a relation of

$$X/R = A/B$$

Similarly, in Fig. 39-3, which diagrammatically illustrates the slide-wire or "meter" bridge, it will be seen that if d is moved along the slide wire until the galvanometer shows no deflection, the resistance values of the two portions A and B of the wire must be in the same ratio as those of the two resistors X and R. The resistance of a uniform conductor varies as its length, and the ratio of the *lengths* of the two sections of the slide wire will therefore be the same as that of the two resistors; so that if R be known, X may at once be determined by applying the above equation in the form:

$$X = \frac{A}{B} R$$

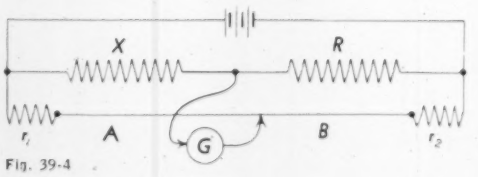


Fig. 39-4

An inspection of the fundamental equation of the Wheatstone bridge brings out the interesting fact that when balance exists, the battery and the galvanometer may be interchanged without disturbing the balance.

While the precision of the Wheatstone bridge as a means of measuring resistance is limited only by its refinement of construction, there are practical limits to the range of resistance values over which it may be used. Nevertheless this range is wide, generally extending up to 100,000 ohms and down to 1 ohm without requiring the use of special instruments.

Slide Wire Bridges.

The slide-wire bridge has a wide application both in the laboratory and in industrial work; and the extended wire may take any of the forms mentioned in connection with the slide-wire potentiometer. Where many similar measurements are to be made it is particularly rapid and convenient in use; and where the variation among resistances to be measured is not wide, the sensitivity may be greatly increased by inserting equal resistances r_1 and r_2 at the ends of the slide wire (see Fig. 39-4). The Roller-Smith general purpose bridge having a straight slide wire (and a telephone headset as well as a galvanometer) is shown in Fig. 39-5. This is a complete outfit. Separate components of a slide wire bridge are obtainable. For example the Leeds & Northrup Kohlrausch design helical slide wire (referred to in the preceding article) may be had by itself as shown in Fig. 39-6. Fig. 39-7 shows a *ratio arm box*—the nucleus of any bridge circuit—made by the General Radio Co., giving ratios from 0.0001 to 1000 in twelve steps.

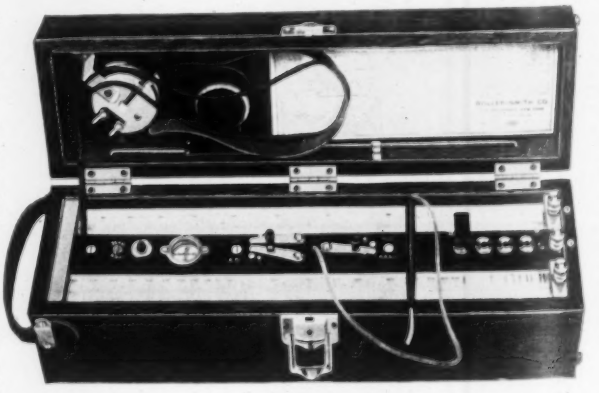


Fig. 39-5

Plug and Dial Bridges

In the Wheatstone bridge, as in the potentiometer, the highest degree of refinement and permanence is obtained by embodying the resistances in standard

Fig. 39-6

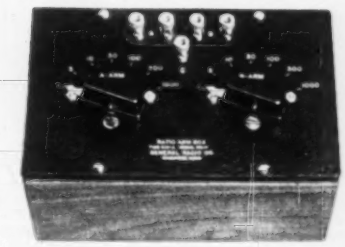


Fig. 39-7

ized units and introducing these into circuit as required, either through a suitable plugging system or by means of dial switches. Although it is practicable to make up a bridge circuit from separate resistance boxes or decade sets (so called because the coils are arranged in groups of ten) the Wheatstone bridge as an *instrument* embodies in a single assembly the three arms which are taken in conjunction with the unknown resistance to form a balanced network.

In some types the coils are permanently in circuit and may be shorted out by metal plugs, while in others the desired resistance values are cut into circuit by plugs or dial switches until the desired values are obtained. Thus, with regard to mechanical construction, there may be said to be two forms of bridge instruments, namely the plug and the dial; and with regard to electrical design, the plug form may be divided into two types, namely the "plug-in" and "plug-out."

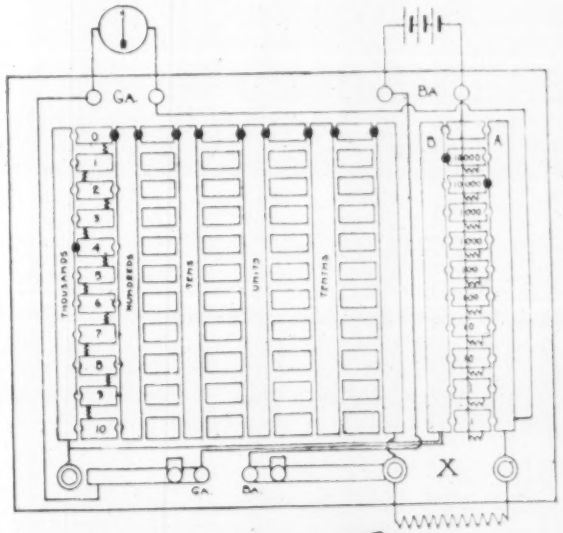


Fig. 39-8

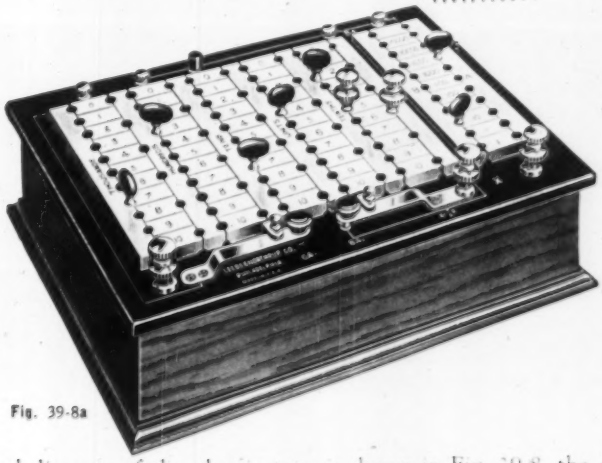


Fig. 39-8a

A typical diagram of the plug-in type is shown in Fig. 39-8, the diagram of the Leeds & Northrup "Anthony Pattern" Wheatstone Bridge. The appearance of this instrument is shown in Fig. 39-8a. Note the ingenious arrangement of plugs and blocks, due to Anthony, whereby the coils may be joined in series or multiple or in various combinations, and whereby coils may be checked against one another in various ways.

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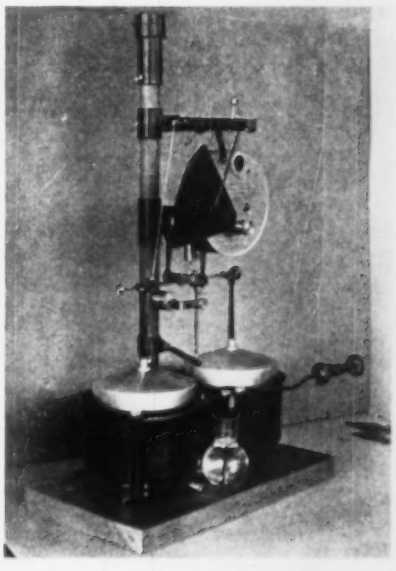

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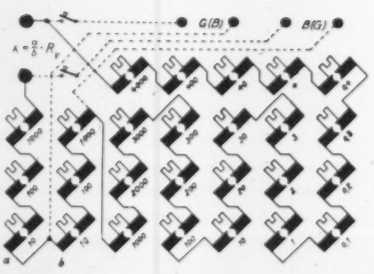

Fig. 39-9

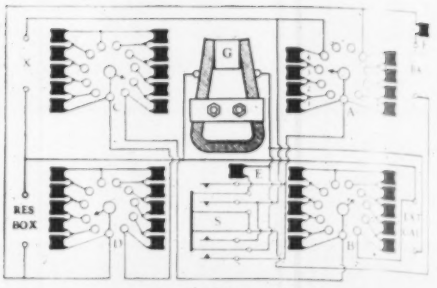

Fig. 39-10

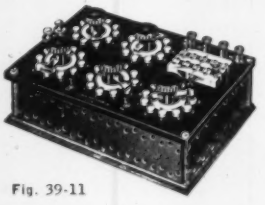

Fig. 39-11

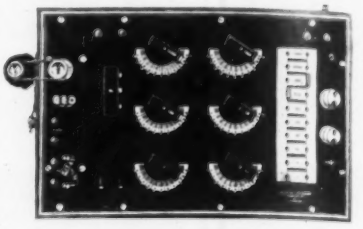

Fig. 39-12

The plug-out type is popular in European practice and Fig. 39-9 shows an interestingly drawn diagram of an instrument of this type manufactured by Siemens (Herman Sticht, U. S. agent).

There are many varieties of dial form bridges on the American market, from inexpensive portable sets to high-grade laboratory standards. Fig. 39-10 is the internal diagram of the Shallcross "No. 630" bridge, and also brings out the Shallcross "sectional spool" construction. Fig. 39-11 shows the Leeds & Northrup "Open Dial" model which has five decades in the *R* arm and two ratio coils of each value for connection in either the *A* or *B* arm. Fig. 39-12 shows a recent and highly refined laboratory Wheatstone bridge made by Eppley which has six 10-coil dials for *R* and two ratio coils in each of five values for either *A* or *B* in an arrangement due to Schöne. Note also the motor for agitating the thermostat-controlled oil bath.

Bridges for High Resistance Measurements

As the values of resistances under measurement approach the order of 1 megohm (1,000,000 ohms), the method begins to suffer because of lack of sensitivity, and because of leakage across the insulation of the instrument. By special provisions these objections can to some degree be overcome, and the useful range of the instrument considerably extended. The logical way to increase sensitivity is to increase the operating voltage of the network. The ordinary laboratory or portable bridge is seldom operated from a source of potential exceeding 12 volts but it is practicable to design a bridge system which will give satisfactory results on a much higher voltage. The best known commercial examples of this type are Evershed's "Bridge Megger" and "Bridge Meg" (J. G. Biddle). The Bridge Megger embodies in one portable outfit a direct-reading ohmmeter,* and a bridge circuit. By means of a change-over switch, the internal circuits are connected as the ratio arms in a bridge circuit, the potential coil is made to function as a galvanometer; and the generator becomes a source of electromotive force, generally operating at half its normal megger voltage. The adjustable or "*R*" arm of the bridge is provided by an external resistance box designed to withstand the relatively high voltage (up to 500) derived from the generator. Fig. 39-13 shows the internal diagram of the Bridge Megger, and Fig. 39-14 shows its appearance. The Bridge Meg is a similar, but more compact instrument, having the four-dial "R" arm incorporated within the instrument.

*Described in Chapter XXXI. See *Instruments*, March 1934, page 54.

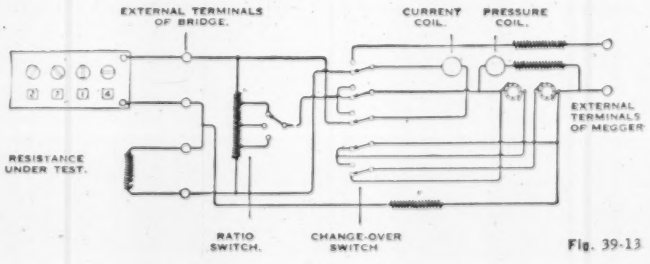

Fig. 39-13

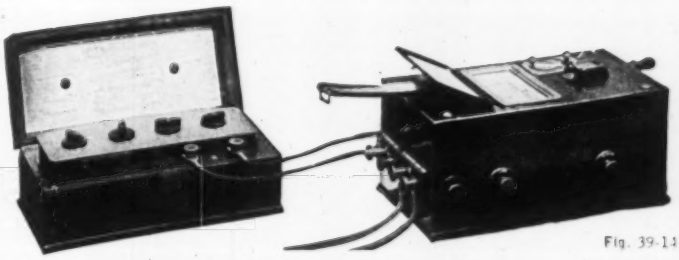

Fig. 39-14

Bridges for Low Resistance Measurements.

Again, in the measurement of low resistances, the Wheatstone bridge lacks sensitivity; and, when determining values of the order of 1 ohm or less, the resistance of the connecting leads and contacts becomes such a disturbing factor that the elementary circuit must be modified. Various arrangements have been proposed employing Wheatstone's essential method, but the most important is a circuit which differs from that of the Wheatstone bridge and which, therefore, will be dealt with in Section 2.

The Unbalanced Bridge. For industrial purposes there are employed standardized temperature-sensitive resistors of definite resistance at a reference point (a given temperature, a given percent of some gas in a mixture, etc.) and the measurement consists in determining the difference between a normal resistance value (corresponding, say, to mid-scale on an indicating instrument) and the value at the time of reading. Similarly, for determining a number of unknown resistances, all of which are known to have values so close to a standard that the particular galvanometer employed in the bridge will never go off scale, a measurement of each individual difference is usually satisfactory. In all such cases the galvanometer may be calibrated in terms of the physical or chemical magnitude. An important advantage is the ease of taking many readings in succession by the use of a multiple switch (example, bringing the temperatures of sixty kettles to a panel in the superintendent's office). An obvious limitation is the requirement for a constant operating voltage. A satisfactorily constant e.m.f. may be obtained, even when using a battery of ordinary commercial dry cells, by (1) placing an adjustable resistor in series with the battery, (2) substituting for X a standard which (with correct battery current) causes a given galvanometer deflection, and (3) using a double-throw or multiple switch to connect successively this standard and the thermometric or other resistors used as measuring elements. All that is necessary to standardize the bridge and its galvanometer, then, is from time to time to connect the standard and adjust the battery rheostat until the galvanometer pointer stands at the mark. The measurements taken immediately afterward will at least be free from the e.m.f. error (though other errors may creep in which the null method would prevent).

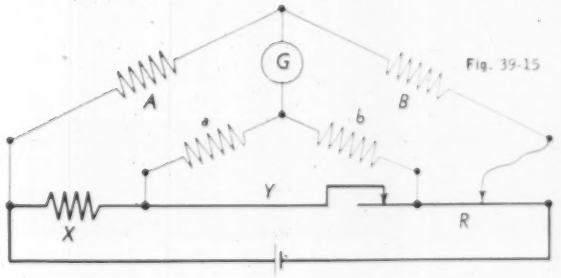

Fig. 39-15

2. The Kelvin Bridge

For the measurement of low resistances (i.e., < 1 ohm) there exist a number of laboratory methods capable of greater precision than the Wheatstone bridge, but the best circuit for general work is that of the Kelvin or Thomson bridge; and there have appeared a number of commercial instruments utilizing it. The Kelvin bridge differs importantly from the Wheatstone bridge in the means employed to nullify the effects of the unknown and inconstant resistances of connecting leads: a system of *double* ratio arms, whereby the resistances of connecting leads are placed in series with high resistance ratio arms and not with the resistance under measurement or with the standard of reference. The basic diagram of the Kelvin bridge is shown in Fig. 39-15. If the resistance A be made equal to a and B equal to b, it may be shown that $X = R \frac{A}{B}$. In an actual instrument, A, a, B and b are resistances of relatively high value, and R is an adjustable low resistance standard. Thus, if R be adjusted till balance is obtained, the value of X will equal $(A/B) \times R$. There are two methods of balancing the Kelvin bridge, and since both cannot be conveniently employed in one instrument, they are the bases of two types of instrument. Balance may

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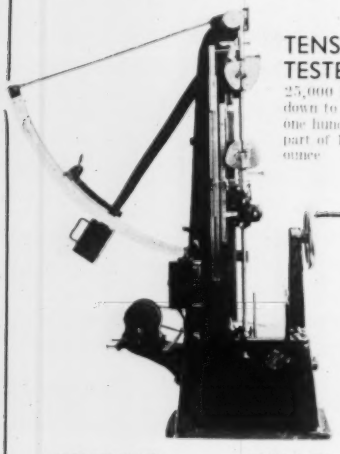

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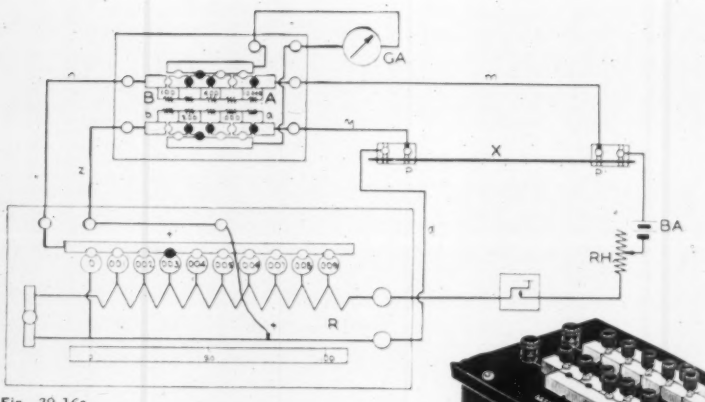

Fig. 39-16a

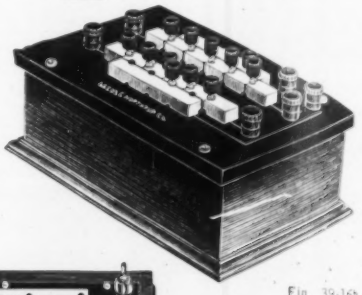

Fig. 39-16b

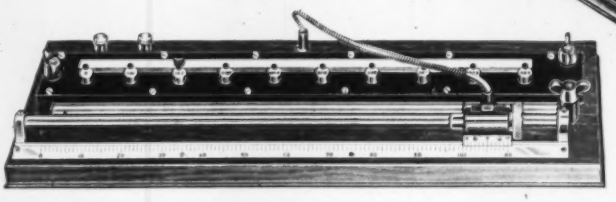

Fig. 39-16c

be effected either by adjusting the standard resistance R, which is usually in the form of a precisely constructed manganin* bar with a sliding contact and a calibrated scale; or by performing a simultaneous adjustment on two of the ratio arms, such as A and a by means of interlocked calibrated dial switches.

In Fig. 39-15, Υ is the "yoke" which is a characteric of the Kelvin bridge. It may be demonstrated that its resistance may be zero, infinity or any value, without affecting the accuracy of Kelvin's method—but the demonstration need not be given here, as it involves taking up various cases, each in lengthy mathematical details.

The complete wiring diagram of the regular (adjustable R) Kelvin bridge supplied by Leeds & Northrup is shown in Fig. 39-16a. Figs. 39-16b and c illustrate the ratio box and the adjustable low-resistance standard, which units together make up the bridge.

The diagram of a Kelvin bridge manufactured by Eppley, in which the standard is *fixed* and the *ratio arms* adjustable, is shown in Fig. 39-17, the instrument itself being shown in Fig. 39-18.

*84% Cu, 12% Mn, 4% Ni; negligible temperature cofficient of resistivity; discovered by Dr. Weston in 1889.

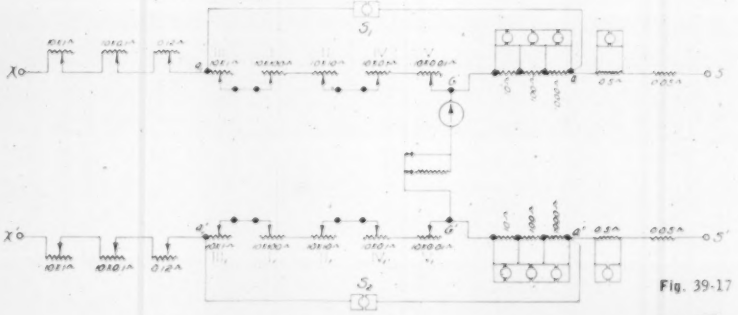

Fig. 39-17

I & I_1 move simultaneously
II & II_1 " "
III & III_1 " "
IV & IV_1 " "
V & V_1 " "

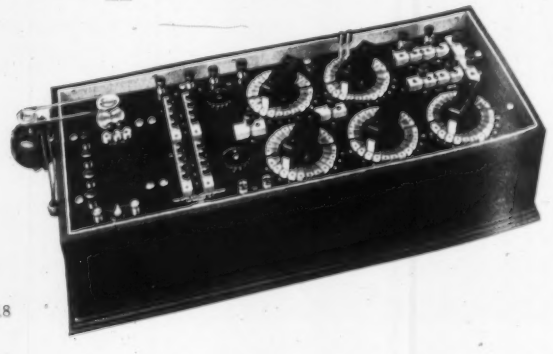

Fig. 39-18

The Hoopes Conductivity Bridge.

A special form of Kelvin bridge, known as the Hoopes conductivity bridge, enables the conductivity of wire samples to be directly determined by comparison with a fixed standard of the same material, which replaces the adjustable calibrated resistance. The bridge is adjusted by moving a contact along the sample; and the operation consists essentially in determining the length of the sample wire that has the same resistance as that of a definite length of the standard wire. In the use of the Hoopes bridge a sample of the wire to be tested is cut to a standard length and weighed on a special scale calibrated to show the excess or deficit in weight of the sample as compared to the standard. When a similar scale on the bridge is manually adjusted to compensate for the discrepancy, and a balance obtained, the bridge reads directly in terms of conductivity of the wire.

3. Fault Location in Lines and Cables (Loop Tests).

The Wheatstone bridge circuit with slight modification may be used for the purpose of locating grounds in lines and cables. Because such tests require that the faulty conductor be looped with a good wire they are known as "loop tests." The most common are described below:

(a) The Varley Test.

This method (Fig. 39-19) requires a good wire reaching to a point beyond the fault, but does not require that it be of the same ohmic resistance as the defective conductor. Connection is made to a bridge as shown, the battery being placed between the junction point of the ratio arms and ground, and the loop in the "unknown" or X arm with the faulty wire next to the adjustable arm. With this connection, earth currents or changes in ground resistance act only to modify the strength of the battery current, and do not directly affect the accuracy of measurement. The ratio arms are made equal to each other and the adjustable arm varied until the galvanometer indicates a balanced condition. Designating the total loop resistance by R and applying the principle of the bridge circuit:

$$\frac{A}{B} = \frac{p+q}{r+x}$$

But $p + q + x = R$, hence $p + q = R - x$ and $\frac{A}{B} = \frac{R-x}{r+x}$

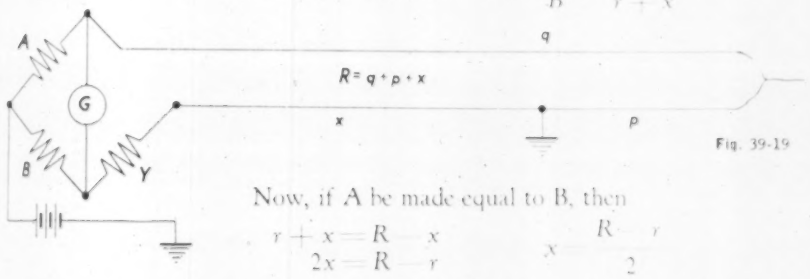

Fig. 39-19

Now, if A be made equal to B, then

$$r + x = R - x \qquad x = \frac{R - r}{2}$$
$$2x = R - r$$

Thus we have a value for x in terms of R and r, both of which we know or can determine. Knowing the dimensions of the conductor we may apply the resistance value x in determining the distance to the fault.

(b) The Murray Test.

This test (Fig. 39-20) is simpler than the Varley test and requires only two variable resistances instead of a complete bridge. It lends itself particularly well to the slide-wire type of instrument. While it is not here necessary to know the actual resistance of the line it is necessary to complete the loop with a wire having the *same* resistance as that of the faulty conductor. This condition is practically always found on communication and power circuits. Connections being made as in the diagram and a balance obtained, it will be seen that:

$$\frac{A}{B} = \frac{p+q}{x} = \frac{R-x}{x}$$

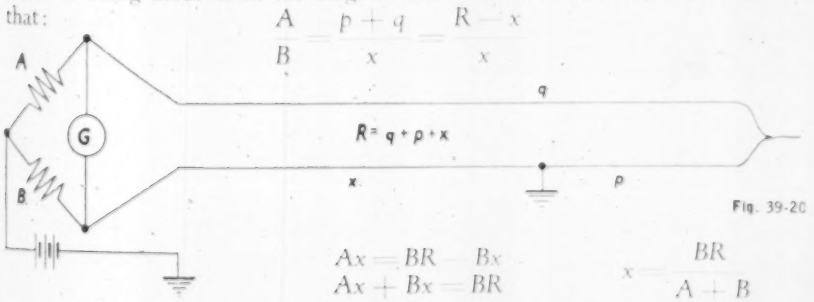

Fig. 39-20

$$Ax = BR - Bx \qquad x = \frac{BR}{A+B}$$
$$Ax + Bx = BR$$

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B346 **General Radio Experimenter.** July-August issue of this house organ contains two articles: "Impedance Matching" and "Amplifiers for Alternating-Current Bridges." General Radio Co., 30 State St., Cambridge A., Mass.

B347 **Large Micro-Metallograph.** 36-page bulletin contains numerous photomicrographs and dwells on the very latest developments in metallographic equipment. Special attention is invited to the arrangement for darkfield illumination by means of which detrimental reflection even in the most difficult cases is avoided. E. Leitz, Inc., 60 E. 10 St., New York, N. Y.

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B349 **Vibration Velocity Meter.** Bulletin covers general principles of electromagnetic device for measuring the velocity of vibration of an object in the noise producing frequency range. The meter is portable and self-contained and employs neither tubes nor batteries, no external power supply is needed. General Electric Co., Schenectady, N. Y.

B350 **Automatic Switches & Controls.** Loose-leaf catalogue: complete data on automatic switches and controls for oil burners, gas burners, unit heaters, coal stokers, pumping equipment, air compressors, etc. Penn Electric Switch Co., Des Moines, Iowa.

B351 **Measuring Resistance of Earth Plates.** Leaflet 195 describes instrument for measuring the resistance of earth plates. Anglo-Swiss Electrical Co., Ltd., 15 Victoria St., London, Eng.

B352 **Photographic Lens.** Leaflet F-132 lists data and prices on Tessar Ic, Tessar IIb and Aero Tessar Ic, Bausch & Lomb Optical Co., Rochester, N. Y.

B353 **Thermostats.** 32-page $8\frac{1}{2}$ x 11" book, "The New Penn System of Temperature Control" prepared for "members of the heating industry" analyzes problems of room temperature control. Penn Electric Switch Co., Des Moines, Iowa.

B354 **Photo Relay.** Catalog 43-950 describing the LE Photo-Relay: application, construction, operation, specifications, advantages, and list prices of these relays. These relays are applicable to all types of industrial control, light control, grading, counting, etc. The relay is available for either a.c. or d.c. circuits. Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

B355 **Portable Hot Cathode Ray Oscillograph.** List No. 1110a describes the operating principle and construction of the instrument. Anglo-Swiss Electrical Co., Ltd., 15 Victoria St., London, Eng.

B356 **Directional Overcurrent Relays.** "Types CR and CRA Directional Overcurrent Relays" is subject of a new 12-page publication, Catalogue 41-505. Intended primarily to sectionalize transmission lines, these relays may also be used for the protection of generators subject to feed-back from other sources. The leaflet contains the most complete information on the subject ever published including a discussion of applications, distinctive features, construction and operation. Also, wiring diagrams, time curves and prices are included. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

B357 **Short Circuit Indicator.** List No. 96 describes instrument for rapidly testing for the presence of short circuited turns in coils wound with copper wire or strip. Anglo-Swiss Elec. Co., Ltd., 15 Victoria St., London, Eng.

B358 **Thermostat.** 4-page bulletin describes Type T17-1 thermostat which operates on an exclusive heat accelerating principle. Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.

B359 **Pressure Regulators.** Booklet which should prove of interest to all industries that require accurate, uniform pressure control, and close regulation of oxygen, acetylene and other gases. Air Reduction Sales Co., Lincoln Bldg., New York, N. Y.

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$$x = BL\ (A + B)$$

Fig. 39-21 is the Leeds & Northrup "Fault Finder," intended for such work but usable as a slide-wire bridge for direct measurement of resistance. Makers of portable Wheatstone bridges usually provide switches whereby these may be adapted for the Varley or Murray loop test.

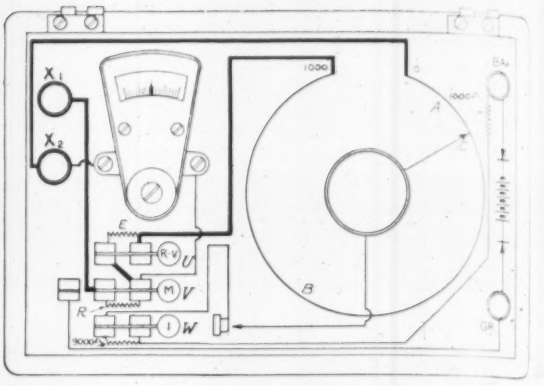


Fig. 39-21

4. Rail Bond Testers, etc.

An interesting and important utilization of the bridge principle is found in the rail bond tester, an instrument for determining the conductance of a rail joint in terms of the conductance of the solid rail. The conductance of the joint may be expressed either as (*a*) the ratio of a given length of the rail including the joint to the same length of solid rail; or (*b*) the length of solid rail which has the same resistance as the joint. The latter is the more common way of expressing the result. Measurement is generally made utilizing the current flowing in the rail; and the operation consists essentially in effecting a balance between the potential drops across (1) a section of continuous rail and (2) a section including the joint to be tested.

In the Roller-Smith bond tester, Fig. 39-22, connection is made to the rail at three points, and a balance obtained by moving the slider along the circular slide wire, which is graduated directly in terms of feet of continuous rail. The resistances between the ends of this slide wire and binding posts 1 and 4 respectively have the effect of extending the useful range of the slide wire. In the Conant bond tester a similar diagram is used, but balance is obtained by moving the outer contact on the solid rail.

Because rail bond testers must of necessity be portable it is not always expedient to provide a galvanometer sufficiently sensitive to respond to the small electromotive forces available when a limited value of current is flowing in the rail. In some forms of the instrument, therefore, the detector takes the form of a telephone receiver in series with a make-and-break apparatus.

A bond tester manufactured by Hartmann & Braun, Fig. 39-23, includes a differential galvanometer with similar opposed windings, and is fitted with a protective resistance to guard the movement against abnormal current in case of an open circuited joint or a very bad bond. The first observation is made with the adjusting knob at P (diagram I) when, if the deflection is not abnormal, the knob is manipulated to give a balance on a calibrated slide wire. The first movement of the sliding contact away from P serves to open a short-circuiting switch (diagram II) and cut both windings of the galvanometer into circuit. The reading on the slide-wire scale gives the joint resistance in terms of a standard length of rail.

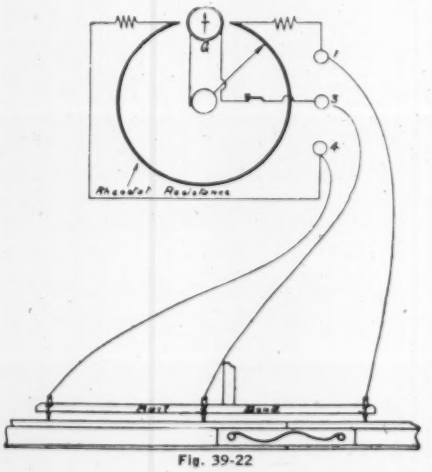


Fig. 39-22

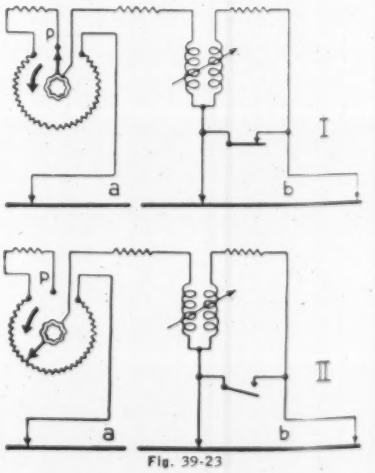


Fig. 39-23

5. Bridge Circuits on Alternating Current

(a) Principles.

If a bridge circuit be wholly free of inductance and capacitance, a balance obtained with direct current in its coils would be maintained if alternating current were substituted for direct and the galvanometer replaced by an a.-c. detector. In most well designed bridges the windings of the individual coils which go to make up the complete circuit are constructed to have negligible inductance and capacitance, so that on commercial frequencies and at low voltages little error would be introduced by reactive properties of the circuits. Bridge networks have long been used for determination of inductance and capacitance; and in the past ten years the principle has found a wide application in the measurement of a.-c. magnitudes such as power, reactive component and power factor, particularly in such work as the determination of losses in insulation, or the characteristics of highly inductive circuits or where very high voltages or frequencies are encountered. Under certain conditions not only does the bridge circuit offer a method more convenient and precise than any other for making the desired measurement, but sometimes it affords the only means whereby the desired results may be accomplished. The a.-c. bridge in such work can hardly be said to come within the scope of industrial measurements; and since it presents many problems of a highly specialized nature the reader is referred to current literature on the subject; some of which is cited in the references below.[1]

(b) Inductance and Capacitance Determination.

Two relatively simple applications of the a.-c. bridge, viz: the measurement of inductance and of capacitance of coils and other circuits, will be given here; but for methods requiring high refinement of technique it will be necessary to refer to the citations mentioned.

Measurement of Inductance.

In Fig. 39-24 is shown a bridge circuit for comparing an inductance with a variable standard of self inductance. L_1 is the inductance to be measured and L_2 is the adjustable standard. A and B are non-inductive ratio arms. Since any inductive circuit must have resistance, it becomes necessary in order to obtain a balance, that the balance be effected for both resistance and inductance; and for this purpose a non-inductive adjustable resistance should be connected in series with one or other of the inductances. A balance is first obtained on direct current, using a galvanometer of the ordinary type, after which alternating current and an a.-c. galvanometer are used, and a balance effected by adjustment of the standard inductance L_2. Then:

$$\frac{L_1}{L_2} = \frac{A}{B}; \qquad \text{Whence} \qquad L_1 = \frac{A}{B} L_2$$

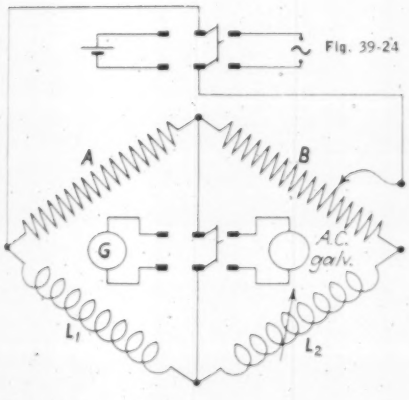


Fig. 39-24

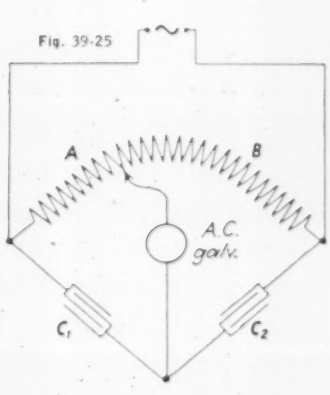


Fig. 39-25

Capacitance Bridge.

Since a capacitor does not form a complete metallic circuit, and for many purposes the power component of the current in such a unit may be neglected, capacitance measurements may be made with a very simple bridge circuit, particularly when it is desired to know the performance of the condenser on alternating current supply only. The circuit is shown in Fig. 39-25, where C_1 represents the capacitance to be measured and C_2 a fixed standard capacitance. A and B are adjustable ratio arms by which balance may be directly brought about when the network is energized from a.-c. source. Then:

$$C_1 A = C_2 B \qquad \text{Whence} \qquad C_1 = \frac{B}{A} C_2$$

NEW INSTRUMENTS

Write Information Section, Instruments Publishing Company, for additional information.

Electronic Relay Telemetering System

Bailey Meter Co.

By transforming minute electrical currents into useful forces, an electronic relay plays an important part in this new telemetering system for measuring pressure, temperature, liquid level, etc., at distant locations. Receiving instrument, housed in moisture-proof pressed steel case, employs "Galvatron" electronic-relay elements (see *Instruments*, June, 1931, pages 76-77) and records as many as four factors on one 12" circular chart. Transmitter consists principally of a variable resistor operated by the measuring element. For example, in a float-operated transmitter for liquid level (Fig. 1) a float rotates a sprocket which operates the rheostat. When necessary, an electric bulb is provided to prevent frost on resistance unit. For distances up to ten miles, accuracy to within 1% of scale reading is said to be obtained by using a 3-wire connection with telephone lines or their equivalent between transmitter and receiver (see Fig. 2). Variable resistance T is adjusted by the measuring element. Resistance P of receiving element automatically balances T so that a pen geared to P moves in accordance with position of measuring element driving T. For distances less than three miles, 2-wire

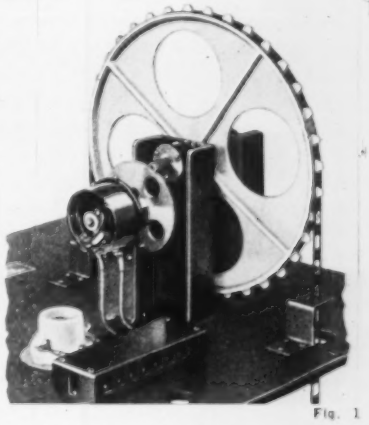


Fig. 1

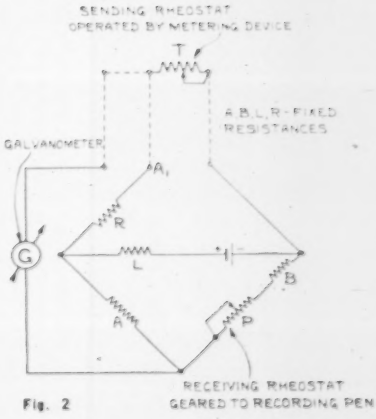


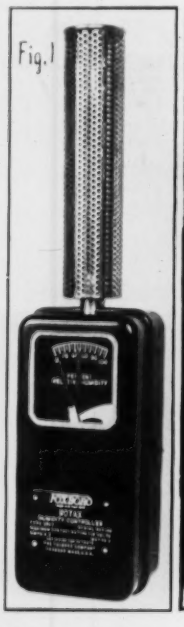
Fig. 2

connection may be used; galvanometer is connected to bridge at A_1. With this method, accuracy to within 1% maximum scale reading is said to be obtained. Only a small amount of current is required because a vacuum tube system amplifies transmitted power sufficiently to assure positive operation. Dry cells, used to produce the necessary d.c. supply, should therefore last from six months to a year. Current and voltage being small and current being direct, there is no danger of interference between adjacent telephone lines and recording circuit; and special filters and insulating transformer equipment are unnecessary.

Relative Humidity Indicating Controller

The Foxboro Co.

FOR plants or buildings having humidifying or air conditioning equipment, newly developed "Rotax Indicating Relative Humidity Controller" is said to combine accuracy of maker's membrane type hygrometric element with advantages of "Rotax" type contacts.



Neither of these units is a new development but their combination now makes available, it is said, features not obtainable previously in humidity controller. Controller, located wherever electric current is available, maintains humidity by operating solenoid valves and motor valves on water, air or steam lines to operate unit heaters, control dampers, air washers, etc. Case houses relay set (see Fig. 2) but its shape is such that minimal space is required for mounting. Uniform contact pressure and self-cleaning action are features of "Rotax" contacts (described completely in *Instruments*, Jan. 1933, page 17). Range of new controller is 0–100% relative humidity and it is designed for use between +10 and +120° F. dry-bulb temperature.

Room or Duct Temperature Controllers can now be furnished in the same style case for any industrial application. Interlocking electrical circuits can be furnished when required.

(c) Instruments

Most a.-c. bridges are "specials" but Fig. 39-26 shows one which is about the most comprehensive self-contained bridge on the market: the General Radio Co.'s "No. 650-A" which is direct-reading over a wide range not only for d.-c. resistance but for a.-c. (1000 cycles) resistance; capacitance and dissipation factor; and inductance and energy factor.

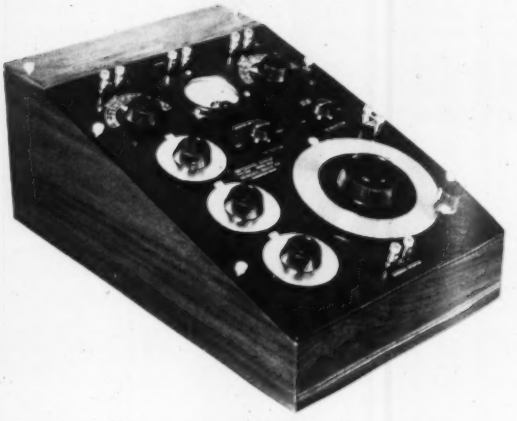


Fig. 39-26

[1] Partial Bibliography on A.-C. Bridges.

Dawes & Daniel. High-Voltage Bridge for Measurement of Cables. *Transactions A.I.E.E.*, Vol. 51, 1932, page 198.

Kouwenhoven & Baños. A High-Sensitivity Power Factor Bridge. *Transactions A.I.E.E.*, Vol. 51, 1932, page 203.

R. P. Siskind. Power Factor Measurement by the Capacitance Bridge. *Transactions A.I.E.E.*, Vol. 51, 1932, page 214.

Balsbaugh & Moon. A Bridge for Precision Power Factor Measurement. *Transactions A.I.E.E.*, Vol. 52, 1933, page 528.

J. G. Ferguson. Classification of Bridge Methods of Measuring Impedances. *Transactions A.I.E.E.*, Vol. 52, 1933, page 861.

T. Slonczewski. A Bridge for Measuring Inductance. *Instruments*, Vol. 7, Jan. 1934, page 2. [Describes an improved Owen bridge.]

Measurement of a Small Inductance. *General Radio Experimenter*, March 1934.

F. R. Benedict. Bridge Methods for Measuring Dielectric, Power Factor and Capacitance. *Instruments*, Vol. 7, May 1934, pages 84-86.

B. Hague. A.C. Bridge Methods. Pitman & Sons, 1932. (Reviewed in *Instruments*, Jan. 1933.)

6. Bridges for Industrial Measurements

Instrumentation's rapid advance in all industries since the First World War has largely been due to the ever-widening use of electrical methods for measuring non-electrical conditions. The direct-deflection method may lead in popularity—in the number of indicating and recording instruments used by engineers; the potentiometric method may shine as a paragon entrusted with the most honorific duties; but the bridge method overshadows others in general usefulness. Its vital importance escapes notice on first surveying these many and varied industrial fields, because—

1. The bridge circuit itself lurks out of sight in bridge type thermometers, air meters, flue gas analyzers, etc.
2. Such instruments are seldom called bridges.
3. Some of these instruments are so designed as to employ a bridge circuit, a potentiometer circuit or a composite circuit, without structural changes.
4. Many of the industrial bridge type instruments do not operate on the null principle but measure unbalance.
5. The self-balancing slide-wire recorders and controllers are customarily called "potentiometers" whether they are being used as potentiometers or as bridges.
6. In all well-built industrial instruments employing bridge circuits for the measurement or control of non-electrical values, the bridge is not only inconspicuous but so "well behaved" that the user generally takes it for granted and devotes his attention to (*a*) the primary element, such as the analysis cell or the thermometric coil, and (*b*) the indicating, recording or automatic controlling devices.

All the more reason, therefore, why a brief outline of bridges for industrial measurements should be given at this point. In the following, we shall leave out construction details, touch only lightly on the (non-electrical) physical and chemical principles involved, and take up only the various bridges as such.

In general it may be summarized that in the plant or for industrial measurements in the field,

1. The manually adjusted bridge is employed where extreme accuracy is desired or where one instrument must cover several ranges of resistance values.
2. The unbalanced bridge finds its most useful applications where only one class of measurements is made, over a fairly narrow range of resistance values.
3. The future belongs to self-balancing instruments, which are opening up new fields of industrial Instrumentation. Their development since the publication in 1925 of Borden's A.I.E.E. Instruments and Measurements Committee paper* on electrical measurements of non-electrical values has been many times greater than in the preceding quarter-century.

*P. A. Borden. Electrical Measurements of Physical Values. *Transactions A.I.E.E.*, Vol. 44, 1925, pages 238-262.

Resistance Thermometry

The resistivity of all pure metals increases with temperature. This relation is not linear, and over a range of several hundred degrees its mathematical expression to fourth-decimal exactitude takes at least three terms, but for several metals it is exactly known. Since the art of protecting a resistance coil in any medium at any non-destructive temperature is well advanced, it is possible to obtain precise temperature measurements by the use of such units (often called "bulbs") connected in a Wheatstone bridge circuit. The metals most commonly used for industrial resistance thermometry are platinum, copper and nickel. Bridges specifically intended for temperature measurement are either of the slide-wire type or employ deflection galvanometers, but all may be calibrated directly in terms of temperature rather than resistances.

The precision with which temperature determinations may be made with the bridge circuit has made it a favorite method for exact measurements in research work and under laboratory conditions. The International Temperature Scale is defined up to 660°C. (1202°F.) in terms of the resistance of a platinum coil. The bolometer devised by Langley nearly half a century ago (a tiny resistance element fixed at the bottom of a tube which is pointed toward a source of radiation) is sensitive to a millionth of a degree Fahrenheit.

Fig. 39-27, the elementary circuit diagram of the resistance thermometer, is self-explanatory. With this simple circuit, the resistance of two copper wires

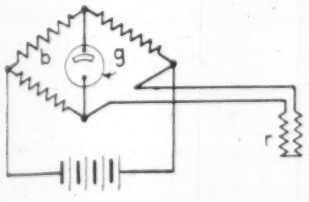


Fig. 39-27

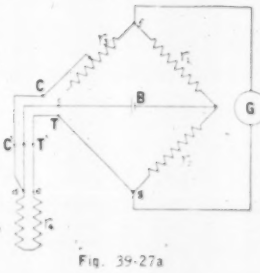


Fig. 39-27a

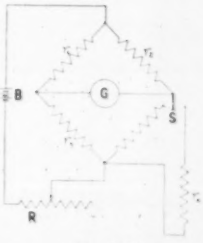
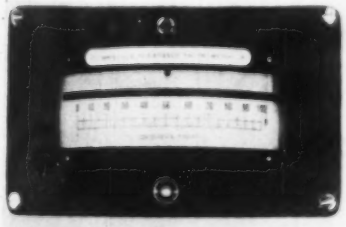


Fig. 39-28

between the coil and the instrument may be a serious source of error where the distance is more than a few feet and the air temperature variable. Fig. 39-27a shows the "Siemens three-lead" method of compensation for a balanced bridge. It requires that copper leads CC' and TT' be of equal resistance — which simply means using high-grade commercial wire — and that r_3 be adjusted to balance the bridge. Fig. 39-28 is the diagram of a widely used temperature bridge, uncompensated for connecting circuit temperature (and therefore requiring low- or constant-resistance leads) but employing a deflection galvanometer. Switch S is periodically thrown to the left, replacing the thermometric coil r_1 by a fixed resistance, and the battery current is adjusted by means of R until the galvanometer deflection is correct for the fixed resistance — as explained in Section 1. In the design of the resistance thermometer it is desirable that the watts loss in the sensitive element be kept at an absolute minimum, so as to eliminate possible errors due to self-heating.

A recent (1934) industrial resistance thermometer (Bristol's) is shown in Fig. 39-29; and Fig. 39-30 is its diagram which combines the convenience of



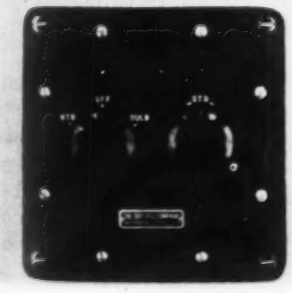


Fig. 39-29

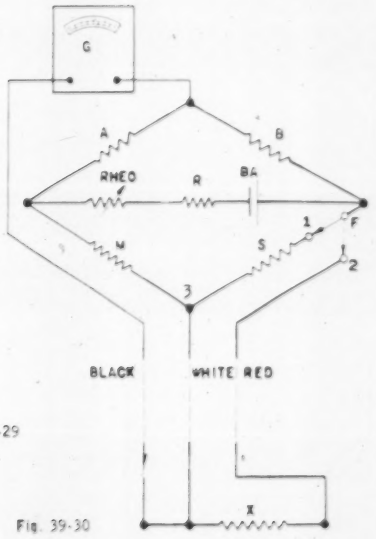


Fig. 39-30

A Stable High Resistance

Westinghouse Lamp Co.

PHOTOMETRY of Mazda incandescent and ultraviolet lamps requires use of a stable resistor as a grid leak in phototube amplifier. To meet this need there was developed a resistor (Fig. 1) with a glass spiral in a bulb filled with an inert gas. A carbon film is deposited by electrical discharge on glass spiral. Thickness of film determines resistance of tube, which can be made any desired value from 10 to 1,000,000 megohms. Said to be particularly useful in various amplifier circuits for measuring small currents or for accurate measurements with an electrometer. Temperature coefficient (negative) is approximately 0.2% C.

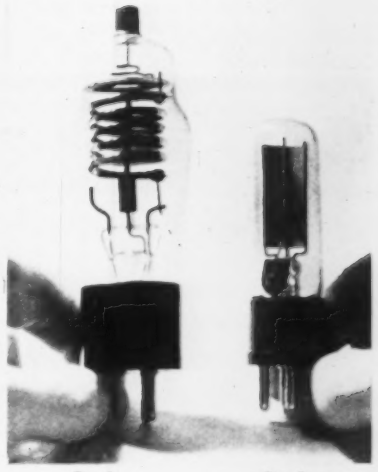


Fig. 1

Fig. 2

Special Phototubes, Etc.

Westinghouse Lamp Co.

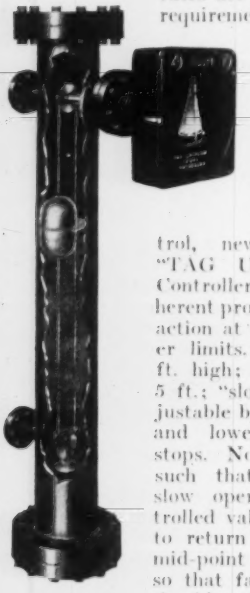
SENSITIVE only to definite bands of ultraviolet radiations, new photoelectric tubes are available in various types with threshold values of sensitivity set at different points in the ultraviolet spectrum so that radiations can be studied qualitatively as well as quantitatively. Among uses are: to test transmission and absorption of various types of glass and solutions; and ultraviolet output of different light sources, in different spectral regions; control of ultraviolet radiation by ultraviolet of certain products for the production of Vitamin D. Another new line includes several of caesium oxide type (Fig. 2) sensitive in the visible range as well as in the infra-red. Available in both vacuum and gas-filled types, these types are suitable for various control problems where tungsten-filament light is activating agent. Other tubes of the caesium oxide design approach eye sensitivity and, therefore, are valuable in color matching and in photometry.

Grid-controlled rectifiers include cold-cathode tubes and a complete line of hot-cathode tubes in both mercury-vapor and inert-gas types. A d.c. voltage regulator, which is a cold-cathode gas-discharge tube and which depends for its regulating properties on a practically constant voltage drop, is finding valuable use for the regulation of voltage for locomotive headlight lamps. A starting tip or "keep-alive" electrode in this tube also permits its use as a d.c. relay or a relaxation type of low-frequency oscillator.

Liquid Level Controller

C. J. Tagliabue Mfg. Co.

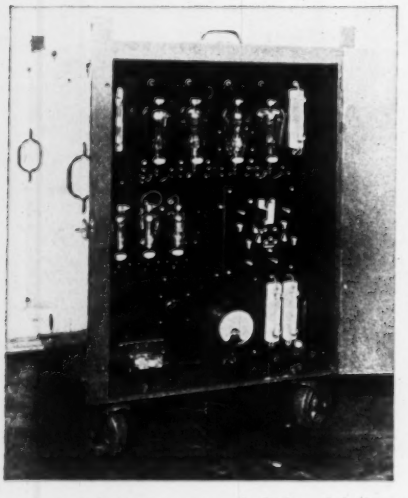
IN certain types of applications, notably where effluent subsequently passes through processing apparatus where heat transfer and evaporation rates are involved, prime requirement is avoidance of jerky control — even if at cost of precise level regulation. Designed especially to give a "smooth" or "averaging" mode of control, new air-operated "TAG Uniflow Level Controller" has also inherent provision for quick action at upper and lower limits. Chamber is 8 ft. high; float travel is 5 ft.; "slow zone" is adjustable by setting upper and lower quick-action stops. Normal mode is such that in spite of slow operation of controlled valve, tendency is to return float to exact mid-point of slow zone, so that fast limit action should seldom occur. Unique feature is radial magnetic coupling (see *Instruments*, May, 1933, page 109) combining small gaps and large active areas.



Ignition Welding Timer

Westinghouse Elec. & Mfg. Co.

FOR timing of all types of resistance welding machines this new portable ignition welding timer is said to be so accurate that it will pass electric current for periods as short as one cycle (1/60 second). It is adjustable up to 30 cycles and is recommended for fabrication of aluminum, aluminum alloys and high strength steels. Makers state that it will play an important part in manufacture of light-weight stream-lined trains, automobiles, airplanes and ships. Dimensions 46"x42"x29". Approximate weight 700 lbs. Will carry as high as 700 kv-a., 440 volts single phase.



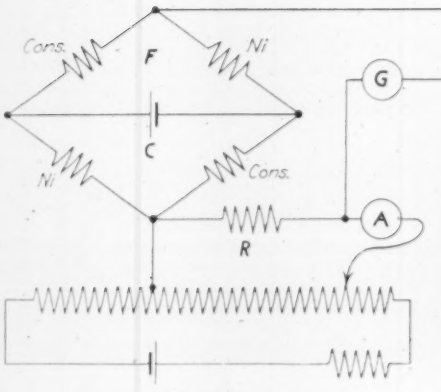


Fig. 39-31

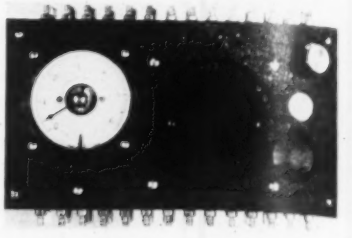


Fig. 39-32

the deflection galvanometer circuit with compensation for temperature of connecting leads.

Fig. 39-31 shows the circuit diagram of a novel form of portable pyrometer, brought out in 1934 by the Lewis Engineering Co., combining the features of the resistance thermometer and of the semi-potentiometer. The unknown e.m.f. E is balanced against the e.m.f. across a resistor R in which the adjustable current is measured by a milliameter A. Balance is indicated by a galvanometer G. In these features the device does not differ from the semi-potentiometers described in the preceding article. The cold end compensator however consists of a bridge circuit F, having arms of alternately high and low temperature coefficient material (nickel and constantan) supplied with a small current from an auxiliary battery C, so that there is introduced into the circuit a current giving the same e.m.f. per degree of bridge-temperature as the thermocouple. The compensation is thus made effective through a wide range and the sensitivity of the instrument is such that temperature may be read as effectively in low ranges as in high. A form of this instrument with a long-range circular scale (for airplane work) is shown in Fig. 39-32.

Measurement of Temperature Differences

While a special form of resistance thermometer, the bolometer, is sensitive to a millionth of a degree Fahrenheit, no instrument can measure a temperature that closely in the sense of assigning such a numerical value as "7.123456° C." because the world's ultimate standard—the International Temperature Scale—stops at the third decimal. What a resistance thermometer can do is to measure a temperature *change* in millionths of a degree. Another striking example of the sensitivity of the bridge, however, is found in the measurement of temperature *differences*. For this important industrial application there is employed a pair of coils and leads, as nearly alike as it is possible to manufacture, and installed identically in every way except that the two coils are located at the two points of temperature measurement and that they form adjacent arms of a Wheatstone bridge circuit. The beauty of this scheme is that all factors other than the difference between the resistance values of the two coils affect the two arms equally in opposite directions and cancel out, so that at all times the extent of unbalance is a true measure of the temperature differential. Then, too, a much higher operating voltage may be used than would be practicable with one resistance coil. In practice, moreover, after making all connections, the two coils may be placed side by side in one oven (or refrigerator) and the galvanometer watched to make sure that the bridge remains balanced at all temperatures so long as both coils are at the same temperature; if not, it is easy to plot a calibration curve, though this seldom is necessary in industrial applications. As a matter of fact, the possible sensitivity is such that when testing for balance with both coils at the same temperature, touching one pair of leads with one's finger tips for a few seconds causes a deflection.

Liquid Level

Various industrial measuring systems are based on using a bridge to measure the resistance of a radiating conductor, the rate of heat dissipation being a function of the measured magnitude. We may start with measurement of liquid level—probably the simplest—using a vertical, electrically-heated, wire whose cooling is proportional to its immersion. In practice a similar wire, parallel to the first but shielded by a tube from contact with the liquid, serves to compensate for variations in liquid temperature. This system may be applied where dimensions are too small for the use of a float, the limit of minuteness obviously

being imposed by capillarity disturbances. At the other extreme, where level is to be measured not in millimeters but in feet, a rugged float operates, through a chain and sprocket, a circular rheostat whose resistance is continuously measured by a self-balancing bridge and indicated or recorded miles away. In other applications, where liquid level is preferably measured in terms of head or altitude by a pressure-measuring device, a bridge type electrical pressure gage (see below) may be used.

Mercury level, which serves in many types of industrial instruments to indicate flow rate, temperature, pressure, etc., is commonly used merely to open or close electric circuits; but it also is used—more importantly—to transmit a measurement by varying a resistance. The use of a vertical high-resistance wire or of a vertical uniformly-wound coil—giving a straight-line relation between above-mercury length and resistance value—is already familiar; and we therefore make particular mention of the interesting fact that square-root, square and other relations are easily obtained.

Pressure

Many forms of elements, in which *contact resistance* is an inverse function of the applied force, have won wide acceptance. Carbon—long used for rheostats where a smooth characteristic is desired—remains the principal material. The carbon-contact pressure-measuring element may consist of one or of two resistors, forming one or two arms of a Wheatstone bridge, so that in this respect there are two distinct types, which we may call the single-resistor and the double-resistor, and their characteristics differ so much (because they are used so differently in the bridge circuit) that they must be discussed separately:

The single-resistor carbon-contact piezometer has the following characteristics: (1) in common with the familiar carbon-pile rheostat, it responds smoothly to small increments; (2) the resistance vs. pressure curves of several supposedly interchangeable devices may differ considerably among one another; (3) the curve of one individual device changes erratically during the first hundred or thousand load cycles and does not exactly "stay put" thereafter; (4) it is sensitive to temperature as well as to pressure and in addition to ambient temperature error there is the internal heating effect of rapid cycles of full-load and no-load—as occurs in an automobile tire. Consequently, while single-resistor contact resistance devices are sometimes used for indicating fairly steady pressures, their principal application is in recording vibrations, accelerations and transients. In this field of measurement of rapid variations of pressure, excellent results are being obtained over a truly enormous range: at one extreme we have the measurement of acoustic energy with a thin-diaphragm-and-carbon-granule (microphone) element sensitive to the fluctuations of air pressure produced by a whisper; at the other extreme we have the measurement of explosion pressures with a resistance element compressed by a piston operating in a cylinder communicating with the explosion chamber of a Diesel engine (or, for that matter, of a twelve-inch gun). Mechanically, the essential difference lies in the ratio of pressure surface to contact surface. Electrically, there need be no essential difference, the instantaneous resistance being measured by an unbalanced bridge with—usually—a short-period mirror galvanometer producing an oscillographic record on a moving film.

The double-resistor type of contact-resistance piezometer permits quantitative measurements on a reliably calibrated pressure scale when its twin resistors are connected as adjacent arms of a Wheatstone bridge circuit (Fig. 39-33). This system was originally developed as a strain recorder by McCollum and Peters at the Bureau of Standards, then developed for engine testing by Martin and Caris at the General Motors Research Laboratory, and finally developed for various industrial purposes and manufactured by Baldwin-Southwark. Its various forms are described in Part Four of this Manual [Chapter XVII, Sec. 16, Art. (a)], but it may be pointed out here

Fig. 39-33

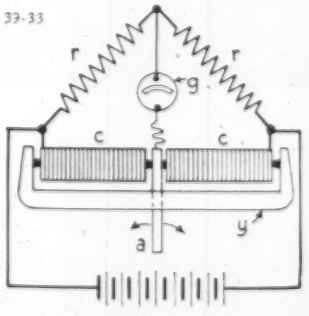
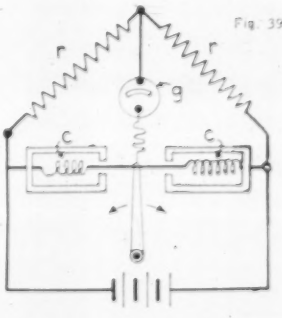


Fig. 39-34



Re-designed Thrustors

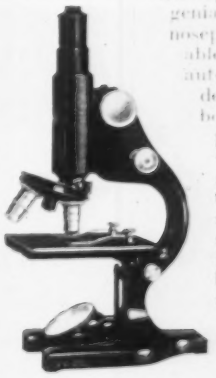
General Electric Co.

IMPROVEMENTS in the G-E Thrustor, a servo-motor that produces a smooth straight-line thrust through a definite length of stroke suitable for operation of clutches, brakes, valves, etc., have been announced. Complete range of standard models provide 10 combinations of thrust and stroke ratings varying from 50 to 3200 lbs. thrust and from 2" to 16" stroke. Impeller housing of centrifugal pump is stationary, a rigid shaft running in ball bearings connecting impeller to driving motor. Various a.c. or d.c. driving motor arrangements are available. For single-phase service, capacitor motors are used on all Thrustors rated 100 lbs. thrust. For 25-cycle service, a special step-up gear train is provided to obtain same impeller speed as with 60-cycle. For 50-cycle supply, impellers of slightly greater diameter are used to maintain rated thrust capacity.

"No. 66" Microscope

Spencer Lens Co.

STANDARD in size but designed and built to come within reduced budgets, new "66B" microscope is equipped with 16 mm. and 4 mm. standard objectives, 10× Huygenian ocular, double nosepiece, sturdy rotatable disk diaphragm, automatic lubricating device for bearings, body tube stop to prevent breaking slides when focussing 16 mm. objective, solid Bakelite stage with spring steel clips, etc. Finish is satin black and chromium and fine adjustment likewise is same as on expensive models. Also available (as "66D") with an additional 6× Huygenian ocular.



Engine Tester

McQuay Norris Mfg. Co.

COMBINES a pressure gage and a vacuum gage in one nickel-plated case and is used for testing internal-combustion engines. Made by U. S. Gage Co. Compression attachment has a check valve for holding pressure to facilitate taking compression readings, and a relief valve for releasing pressure before taking next reading. Vacuum gage part is complete with 3-ft. rubber hose and special manifold attachment. Compression scale (inner one on dial) is supplemented by zone markings ("normal," "fair" and "poor") on the glass, which may be rotated to a definite position corresponding to the particular rating of the motor being tested. Gage can of course be used for other purposes.

Welding Timers

The Electric Controller & Mfg. Co.

1. AUTOMATIC WELD TIMER

FOR use with resistance welding machines, Folio 2 EC&M Automatic Weld Timer, Fig. 1, operates on same principle as Folio 1 Weld Timer, *i. e.*, recognizing variables entering into welding circuit and timing the weld with respect to the current flow, but it contains less apparatus, the dust-tight enclosing cabinet is smaller and not as deep, and operation is twice as fast. In addition to adjusting dial for varying time, new timer is also equipped with a means to provide a triple current range, by inserting a plug into one of three receptacles. These two adjustable features should not be confused with the automatic time-varying characteristic: they merely allow selection of best operating conditions for work and heat tap. When so adjusted, timer varies time in inverse proportion to rate of current flow.

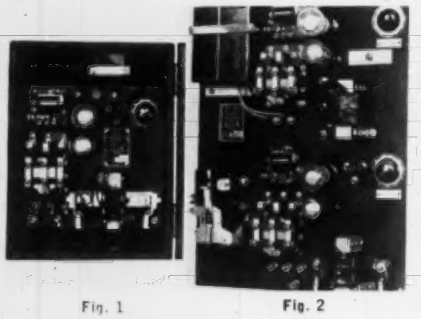


Fig. 1

Fig. 2

2. AUTOMATIC REPEAT WELD TIMER

FOR use in connection with resistance welding machines in which electrodes of welder are air- or motor-operated, EC&M Automatic Repeat Weld Timer, Fig. 2, differs from standard EC&M Automatic Weld Timer in that it has an additional timing circuit for governing length of time electrodes of welding machine are separated to allow work to be moved to position where next weld is desired. "Welding-period" varies in inverse proportion to rate of current flow while "off-time," period electrodes are apart, is a definite length of time which is adjustable. No need to vary lengths of cams: there are two separate electrical circuits easily adjustable and independent of each other. Fig. 2 shows this new Repeat Weld timer removed from dust-tight cabinet. On right side are adjusting dials for the "off-time" and "welding-time." Below upper dial which governs "off-time" period, is a small double-throw snap switch which permits timer to be set for automatic repeat or single-shot operation.

The Eupatheoscope

E. E. Free Laboratories

BODILY comfort in a room depends not only on air temperature but on circulation, humidity and purity of air, and on temperatures of walls and other surfaces radiating heat to (or absorbing radiant heat from) the clothed human body. The eupatheoscope (from Greek for happiness) is said to be "a recent invention by British government scientists to determine the comfortable or uncomfortable character of the *air* in a room." In reality it is a combined kata-thermometer and calorimeter totalizing heat loss, from a simulated average

that it is the arrangement of the twin resistors as the variable arms of a Wheatstone bridge which eliminates or minimizes the most troublesome errors: the two piles are as alike mechanically as possible in precision manufacture with rigid inspection, and they are placed under an initial stress, so that the force under measurement produces in one pile an increase of resistance and in the other a decrease of resistance. On the other hand, temperature and other disturbances cause either an increase or a decrease of resistance in both arms—the same in both arms, hence balancing out and leaving the ratio unchanged.

Small Displacements.

The ideal means of converting minute mechanical motion into an electrical magnitude, with perfectly linear relation or with a characteristic obeying an exact scale law, remains uninvented in spite of the great need of it in industrial Instrumentation. An application of the capacitance bridge, however, consists in making the X arm take the form of a capacitor so designed that a microscopic change in the distance between its plates unbalances the bridge. The precision of this method increases with the frequency of the alternating current and the true "ultra-micrometer" calibrated in millionths of an inch employs a tuned high-frequency circuit which lies outside the scope of this book. There are various practical methods, however, employing d.-c. bridges of types described in the foregoing sections, whereby a minute motion of a lever effects a change of resistance in one resistor, or a change of resistance ratio in twin resistors, as discussed in the preceding paragraph—but with the difference that in this class of applications the mechanical force required must be extremely small. Fig. 39-34 shows the electrical features of an English "hot wire micrometer" in which two small enclosing cells each contain a loosely wound helix of copper wire. These coils are connected mechanically and electrically by a fine straight wire which holds them under slight tension. This wire forms the point of attachment of the member the motion of which it is desired to measure, and of the galvanometer in a Wheatstone bridge circuit. The two coils form adjacent arms of the bridge. An axial movement of the connecting wire, which lengthens one coil and shortens the other, changes the ratio between radiating surface and heat generated by the bridge current, alters the relative temperature of the coils, and produces a change in the resistance ratio. It is claimed for the device, that there may be obtained a magnification of one thousand times between the original motion and the deflection of the indicator.

Rate of Flow of Fluids

A hot object in a fluid stream cools at a rate which is a function of the stream velocity—other factors remaining constant. The cooling rate of a hot wire in an air current is proportional to wind velocity (hot-wire anemometer). An electrically heated wire in a gas stream cools at a rate proportional to gas velocity and gas density and inversely proportional to gas temperature; but the quantity (weight) of gas in a given length of conduit is proportional to its density and inversely proportional to its temperature, so that the cooling rate of a wire across the conduit is proportional to the quantity-rate of the flowing gas. Equilibrium temperature of wire is that at which continuous dissipation of heat energy equals electrical energy supplied. Metal resistivity increasing with temperature, a bridge may be used to measure wire temperature, hence velocity $\times$ area $\times$ density $\div$ gas temperature, hence gas quantity-rate.

These few lines summarize many pages of Part Six of this Manual but suffice to show the validity of hot wire methods in flow measurement. In the King gas meter, Fig. 39-35, although a bridge is used to measure the resistance of the hot wire, the actual measurement is that of the current required to maintain the wire at a fixed temperature, which is done automatically. The Thomas gas meter, Fig. 39-36, likewise departs from the simple hot-wire anemometer. It is based upon the measurement of the amount of heat required to raise the

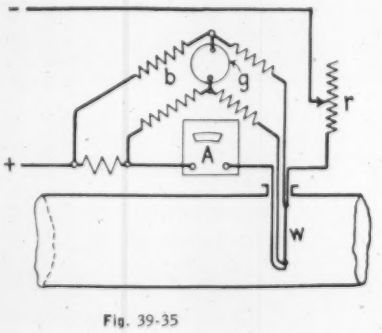


Fig. 39-35

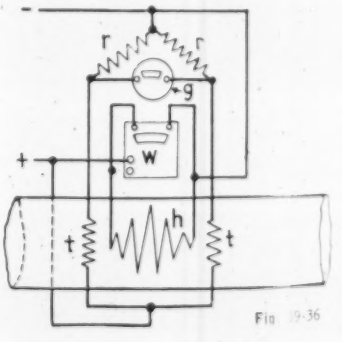


Fig. 39-36

temperature of the gas through a known range. Two similar resistance thermometers, forming two arms of a bridge, are inserted in the main, and between these is placed a heating element. Both the heater and the resistance thermometers are well distributed over the cross section of the pipe. While this meter has a number of forms, its commercial arrangement is such that a constant temperature difference is maintained between the two resistance thermometers by means of adjustment of the current flowing in the heater, and measurement is made of the power represented by this heating current. The meter reads either in pounds or in cubic feet at any desired pressure and temperature. It is manufactured by Cutler-Hammer.

Gas Analysis

In Bureau of Standards Report No. 249, Palmer and Weaver list thirteen desirable characteristics that should be possessed by an ideal gas analysis method. The thermal conductivity method is assigned first place (out of five methods reported on) for nine characteristics, and last place for only one, namely independence of calibration. It is the most important industrial application of electrical resistance measurement as a means of determining a non-electrical ratio. The principle involved is similar to that of the hot wire anemometer referred to in the preceding paragraph, but the electrically heated wire is in a closed cell. The dissipation of thermal energy is accomplished by radiation, thermal convection and by conduction through the surrounding gas, but radiation and convection can be discounted. The equilibrium temperature attained by the wire depends on the ability of the gas surrounding the wire to conduct heat. If the wire used has a high temperature coefficient of resistivity, its resistance will have a value corresponding to the thermal conductivity and therefore to the composition of the surrounding gas. By comparison of the resistances of two such wires, surrounded respectively by a reference gas and a qualitatively known gas mixture, the quantitative composition of the mixture can be rapidly and accurately determined. The outstanding industrial application of this method is the CO_2 meter, of which a simplified diagram is shown in Fig. 39-37. The usual form of twin cell consists of one metal block with two similar cavities, to equalize gas temperatures and otherwise eliminate errors. In addition to flue gas and internal-combustion engine exhaust gas analysis for CO_2, the thermal conductivity bridge is employed for other gases. An unusually versatile portable set made by Engelhard and called "Gasalyzer" is said to be able to "measure acetone, butane, CO_2, CO, hydrogen, helium, methyl alcohol, ammonia, sulphur dioxide in air; NH_3 in H_2N_2; O_2 in H_2; H_2 in steam; CO_2 in a mixture of hydrogen, methane, carbon monoxide, nitrogen and CO_2."

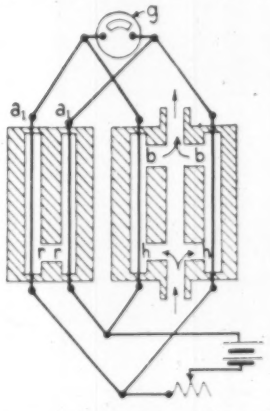


Fig. 39-37

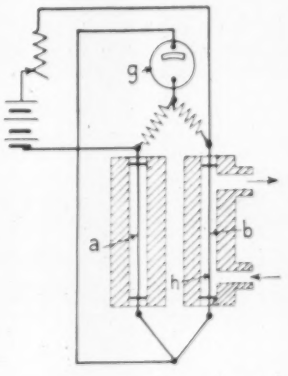


Fig. 39-38

Another type of gas analysis bridge employs a similar electrical resistance ratio scheme but the physico-chemical principle is not that of thermal conductivity but that of catalytic combustion, so that the method is only applicable where there are combustible constituents. It therefore finds its principal application in the measurement of unburned constituents in flue gas. As in the thermal conductivity bridge, there are found the two wires in adjacent chambers (see Fig. 39-38) forming a part of a similar circuit. Here, however, the wires are kept at a much higher temperature than in the CO_2 analyzer, so that the conductor in the active chamber serves as a catalyzer and ignites any CO which may be present. The rise in temperature due to the combustion is much greater than any effect of change in heat conductivity of the gases, completely overshadowing any change due to the presence of incombustible components and furnishing an almost perfect indication of the presence of CO, or, to be more precise, of $(CO + H_2)$, in which terms the instrument is sometimes calibrated.

clothed human body, not only to the surrounding air but to all radiating and absorbing surfaces. Photograph shows it being demonstrated by Dr. Free at Sept. meeting of Electrical Ass'n of N. Y. It consists of a hollow copper cylinder with outer surface of high emissivity coefficient (highly sensitive to temperatures

of surrounding walls and other solids and relatively insensitive to air temperature) enclosing an electric element and thermostat for keeping cylinder at a constant temperature, usually that of the average human body. Heat loss is measured by a watthour meter. "If too much heat is lost, the room would be too chilly for human comfort. If too little heat is lost, the room would be too hot."

Electrical Packless Valve

A. F. Hoppe Engineering Co., Inc.

DESIGNED primarily for control of high pressure liquids (<1500 lbs./in.²) this valve is quick acting, the current being applied only when it is

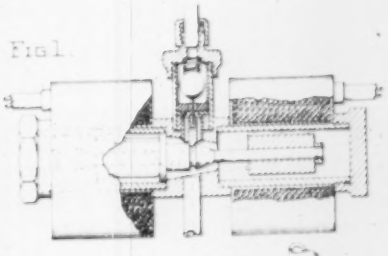


Fig. 1

being opened or closed. Fig. 1 shows it in open position. Valve has two plungers and a sliding shaft carrying them. When one coil is energized, the plunger cooperating therewith slides on shaft until it strikes shoulder at end, thereby driving shaft with plunger. If valve is opening, movement of shaft will force vertical plunger, located beneath ball, upward and unseat ball valve. Sliding shaft has a radius on which vertical plunger rides, thus lifting ball from its seat or permitting it to close when shaft is moved in opposite direction. If valve is closing, opposite magnet is energized, which draws opposite plunger and shaft in opposite direction and allows vertical plunger to ride down the radius and lets the ball seat. Fig. 2 shows manner of mounting plungers.

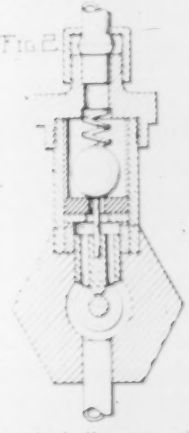
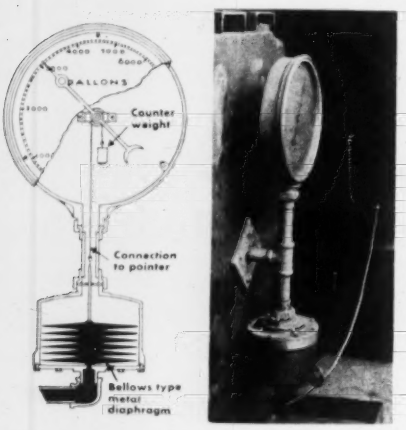


Fig. 2

Industrial Tank Gage

Imperial Instruments, Inc.

SPECIALLY designed for measurement of liquids used in process work, this new instrument employs the hydrostatic principle, being essentially a weight-loaded bellows type pressure gage indicating liquid head in terms of volume. Scale is graduated for particular shape of tank and for particular liquid, and calibrated at a definite temperature

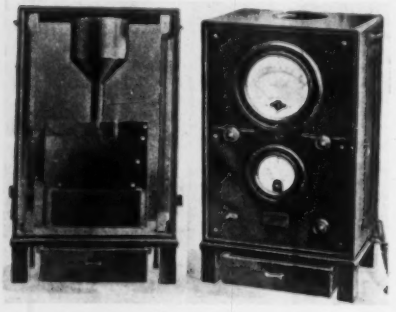


(60° F. in case of gasoline, corresponding to trade practice) which simplifies problem of keeping inventory records. Where the liquid is under vapor pressure or partial vacuum, compensation is effected by connecting bellows housing with top of tank, thus converting gage to differential type correctly indicating liquid head. These gages are built to measure liquids in tanks ranging in capacity from 300 to 3,200,000 gallons. Practically any type of liquid can be measured except those that tend to solidify when standing, or those that attack the phosphor-bronze bellows.

Dielectric Moisture Meter

Thwing Instrument Co.

BASED upon the dielectric constant of the tested material, which is a function of its moisture content. A sample of definite weight is taken from the grain or other material. (This weight differs with different materials and types of instrument.) Sample is poured into funnel at top, and emptied into electric chamber by a quick pressure on top button; apparatus having previously been adjusted according to instructions, percentage of moisture will now be shown directly by a pointer. This reading has thereafter to be corrected for temperature in accordance with a scale on the apparatus. The whole operation takes only a few minutes. It is said that



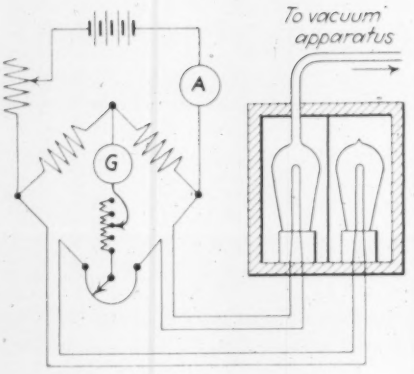


Fig. 39-39

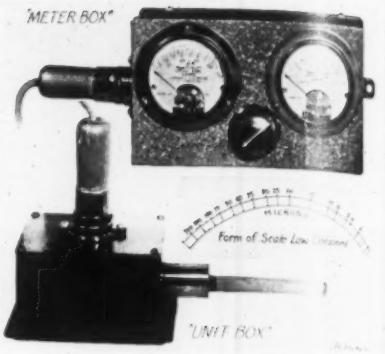


Fig. 39-40

High Vacuum.

For measuring low absolute pressures within the applicability range of a thin diaphragm, the carbon-granule contact-resistance method mentioned under Pressure may be used. But for accurately measuring extremely low absolute pressures in the lamp and thermionic tube industries and other high-vacuum applications, the hot wire or Pirani gage is frequently employed. The hot wire method has already been described under Flow Measurement where the gas density factor was mentioned; and under Gas Analysis it was brought out that the equilibrium temperature depends also on the nature of the particular gas mixture. At ordinary pressures the thermal conductivity of a gas at rest (not of a gas stream) does not vary with pressure changes, but high-vacuum conditions are extraordinary in that gas molecules travel back and forth between the walls of an enclosure such as a vacuum tube without colliding with one another. (The probability ratio in a two-inch tube is so nearly zero as to be negligible). Heat is conducted to the wall from the filament by every molecule that strikes the filament, for it will next strike the wall. The energy loss from the wire thus varies with the number of molecules—as does the pressure. If the pressure is halved, the energy loss through conductivity will be halved, and since the wire is heated electrically, resistance measurement becomes a simple and reliable procedure. A pair of similar hot-wire tubes is used; one tube communicating with the vacuum apparatus and the other containing gas or air at a known absolute pressure; and the two wires forming adjacent arms of a Wheatstone bridge circuit (see Fig. 39-39). The galvanometer is usually calibrated for neon, nitrogen or whatever other gas is used, but when changing to another gas it suffices to change galvanometer sensitivity, calibration curves being linear below 80 microns. The hot-wire method, originated by Pirani some twenty years ago, has been highly developed in the GE Research Laboratory by Dr. Dushman, whose publications on the subject are recommended as the most authoritative. Several pages in Part Four of this Manual are abstracted from his writings. Various forms of Pirani gage tubes have long been on the market, and complete outfits ready for use have recently made their appearance, the one brought out in 1934 by the Continental Elec. Co. being shown in Fig. 39-40.

"The Most Valuable Handbook in My Technical Library"

So say many who have bought it—in spite of its title which suggests "well-known stuff."

Many instrument men, when they see this title, "Fundamentals of Instrumentation," assume that this is a topic on which they have little to learn. The assumption is natural, because everyone who has had years of experience with instruments does know a lot. You, for example, know much more about certain subjects than does "the other fellow." BUT—"The other fellow" knows more than you do about *his* specialties.

There are, then, certain fundamentals that every ambitious and self-respecting engineer, industrial executive or research man should know.

You will find *all* of these in "Fundamentals of Instrumentation." The price is two dollars postpaid. INSTRUMENTS PUBLISHING CO., 330 West 42nd St., New York City.

"variations in the current to the extent of 5% on each side of the 220 volts d.c. for which the apparatus is made" do not impair accuracy. Apparatus can be adjusted to give figures according to drying methods formerly used; does not need any special laboratory as it can be set up wherever electric current is available. All types are to be used on 220 volts d.c. For use on a. c., a small handy rectifier is furnished at low cost.

Operation:

1. Switch current on to apparatus 3-5 minutes before measuring.
2. Turn knob on left to "Adjustment" position.
3. Turn "Adjustment" knob on right to adjustment value.
4. Turn knob on left to the "Measurement" position.
5. Weigh off 110 grams of grain and pour it into funnel at top.
6. Read off percentage of water on scale.
7. Sample of grain is emptied out of apparatus by pulling lowermost handle (it is recommended to take a quick reading and then empty the condenser; grain left in the apparatus gets heated).
8. Measure temperature of grain sample. Read off correction on table and add or subtract from percentage obtained under 6.

Apparatus is available in several models in this country for grain, brewing, milling, drying and other industries.

Photoelectrically Balanced Industrial Instruments

By C. Owen Fairchild*

1. RECORDER-CONTROLLER

IN the March 1934 issue of *Instruments* there was described a radically new type of recording instrument capable of service either as a potentiometer or as a Wheatstone bridge. Its operation and the advantages in using a mirror galvanometer and photocell were fully explained; space will not permit a repetition here. It is convertible into a 3- or 5-position controller merely by connecting three wires. The new recorder-controller, Fig. 1, designed to take care of severe cases of application lag, approaches the ultimate in elimination of hunting, through simple additions: a control-setting slide wire, a cam-operated thermocouple switch and a cam-operated control switch. As applied to a motor-driven valve a single reversible motor is used.

The controlling action of the instrument is easily explained without reference to the previous article or to further details of design. With a thermocouple connected to the recording slide-wire the contact-carriage follows the thermocouple temperature and records it. If this temperature increases or decreases, the control motor decreases or increases the heat supply in proportion to the change. This mode of control is maintained about 95% of the time, effectually counteracting drift. At intervals the control setting potential is substituted for the thermocouple emf., and the contact carriage is brought to the correct or normal point (if it has been thrown off by a sudden change in heat supply or demand). During this brief interval the control motor is disconnected. Then the thermocouple and control motor are reconnected, the contact-carriage returns to the thermocouple temperature and the control motor corrects the heat supply in proportion to the just-measured departure from normality.

Suppose for example that there is a sudden temporary increase in heat demand. As soon as the temperature starts to fall the heat supply starts to increase, and this continues until the temperature stops falling and starts to rise. Now, even though the temperature be low, the heat suppiy is decreased with the rising temperature. Superposed on this action are periodic tests to determine whether the temperature is below the control point, and a proportional correction is applied, increasing the heat supply; then the reduction in heat supply immediately begins again while the temperature is rising. Presently, as the temperature nears the control point on the low side, the corrections made to counteract the rising temperature begin to overtake those made for a low temperature, and the heat supply approximates the correct value at the same time that the temperature reaches the control point. It follows that overheating is eliminated or minimized while a rapid return from abnormal disturbances is accomplished. In other words, the system considered as a thermal oscillator can be effectively damped; and it will be noted from the foregoing that (1) a feature of the instrument is the absence of a follow-up mechanism, or of any mechanical device for limiting the rate of return to normal; and (2) that the response to initial departures is inherently sensitive.

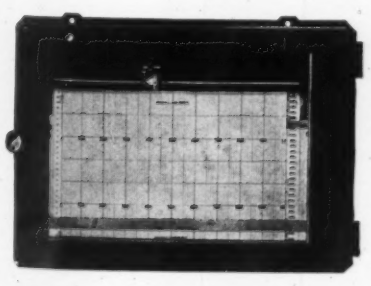
The new recorder-controller is available for either electric- or air-operated valves or electrically heated apparatus but is not available in multiple point. Its control system is not available in a non-recording control instrument.

2. INDICATING CONTROLLER

IN this new potentiometric instrument, Fig. 2, a reflected narrow beam of light from a mirror-galvanometer plays on the edge of a shield in front of a photocell. A slight deflection of the beam from this edge instantly closes or opens the power circuit, without the delay which characterizes the usual combination of a pointer galvanometer with a mechanism. For laboratory purposes the instrument may be supported free from vibrations to utilize its full sensitivity, as required to control a bath to a small fraction of a degree. For industrial use, on the other hand, vibration improves control and the limiting factor is wear on the relays, which can be operated as fast as the particular furnace can be heated or cooled a fraction of a degree: in the absence of a muffle, on-and-off control may wear out relays too rapidly unless the sensitivity is adjusted to permit a one or two degree differential. In the presence of a lag, as in a muffle furnace, 2- or 3-position control hook-ups give results comparable to those obtained with the relatively expensive type of instrument described above. The only moving parts of this controller are the galvanometer and relay. The photocell, of course, is not a calibrated element of the measuring circuit; and it and the amplifying tube will last years unless broken. The lamp is designed for 10,000 hours at normal voltage. The photocell circuit is identical with that shown in the March 1934 *Instruments*, except for a slight modification of the relay connections. For indicating temperature (or emf.) a portion of the light beam from the galvanometer is intercepted by a 45° mirror and reflected upon a screen above the visible portion of the circular slide-wire scale (see Fig. 3), making the action of the controller readily visible at a great distance. The scale and slide wire are 15" long, so that unusually open scales with suppressed zeros can be supplied. As an electrical measuring instrument the accuracy is 0.1%. Models available are for on-and-off 2- and 3-position control, in single or double range for thermocouples and resistance thermometers.

3. INDICATOR

THIS indicator for measuring temperatures with thermocouples or resistance thermometers is calibrated to 0.1% of full scale, has an accurately reproduced circular scale 15" long, is easily balanced and read with the bright line of light showing in the window just over the scale, is rugged enough for severe plant service and accurate enough for laboratory measurements. Readings can be taken quickly because the galvanometer has a short period and ample sensitivity the light beam being equivalent to a pointer 10" long. On a laboratory table it can be balanced and read by an observer either seated or standing; on a factory panel it can be read in poorly lighted places, in fact in the dark. Its outside appearance is like that of the indicating controller, Fig. 3. This new indicator is available in all the standard arrangements such as single or double range, suppressed zero, etc.



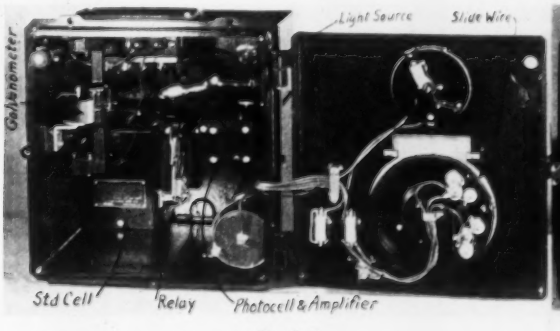


Fig. 2

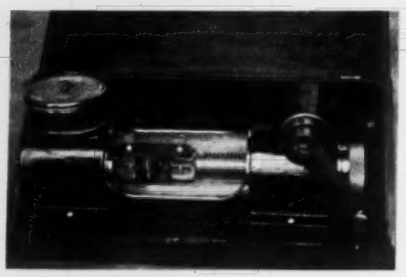
Fig. 3

*Director of Research, C. J. Tagliabue Mfg. Co., Brooklyn, N. Y.

Portable Tensile Tester

Detroit Testing Machine Co.

OF 4000 lbs. capacity yet weighing only 25 lbs., this new testing machine is said to combine portability with the accuracy and other essential features of larger laboratory machines. In addition to obvious advantages for field work it is recommended as an aid to salesmen and other demonstrators as

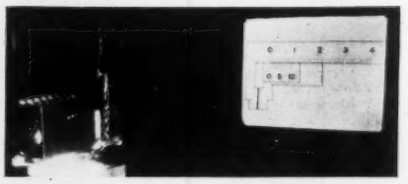


it may readily be adapted to testing all kinds of specimens within its capacity. For laboratory purposes it is simply fastened to a bench or table top. Neat carrying case measures approximately 5" x 7" x 15".

Universal Stirrer

American Instrument Co.

THREE shafts are brought out of motor- and gear-housing; one is direct-connected to motor shaft for high speed (4500 to 11,500 r.p.m.), the others give speed ranges of 750 to 1920 and 125 to 320 respectively. Adjustable mounting (swivel joint and dovetail clamp ring) permits motor to be turned readily so as to bring any desired shaft in position—either vertically as illustrated, or at an angle. While any one shaft is being used for stirring, either or both of others may at same time be used with pulley or flexible shaft for driving other apparatus. Universal motor is rated 1/40 h.p. at full load, speed drops to approximately 2/3 of no load speeds given above.



Vernier Demonstrator

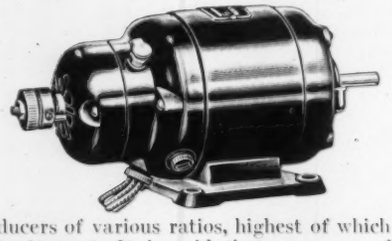
Thwing Instrument Co.

DEVELOPED at University of Pennsylvania to replace unwieldy large vernier models, this new device fits into place normally occupied by slide carrier. Vernier scale is printed on one of a pair of clear glass plates, main scale is printed on other. Adjustment screws project at end and are easily operated in the dark.

Speed-controlled Motors

Bodine Electric Co.

IN addition to ratings <0.1 h.p. there are now announced ratings ranging from 1/10 to 1/4 h.p. New line is available in series and compensated series types with an approximate speed range from 500 to 7500 r.p.m., also available with built-in worm gear speed re-



ducers of various ratios, highest of which is 60 to 1. It is said that accuracy of speed control closely approaches the constancy of synchronous motors; not readily affected by variations in load within capacity. Electric governors are of two forms—form "R" can be adjusted while the motor is running; form "S" only at standstill.

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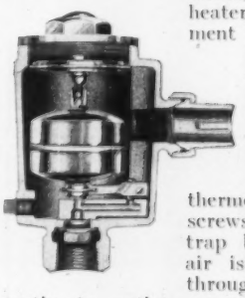
of permanent accuracy." Accuracy claim is ±1%. Designed for use with a standard 50-ohm instrument movement. Ranges: 5-10-50-100-500-1000 volts with a 0-1 milliammeter. Multiplier being non-capacitative and non-inductive, use of a rectifier type milliammeter permits a.-c. voltage measurements. Bakelite case measures 3" x 4½" x 1½". Selector switch has phosphor-bronze contact members with silver contact points. Binding posts are insulated.

Drip Trap

Jas. P. Marsh Corp.

DESIGNED for removal of air and condensation from short steam mains, branches or risers. Said to be especially desirable for unit ventilators, small unit heaters or other equipment which may be subjected to freezing when inoperative in winter. Outlet discharge valve is water sealed at all times; thermostatic element screws directly into trap body. Normally air is discharged through a port directly to outlet connections of trap. Body is provided with one ¾" union nut and tail piece inlet connection and one ¾" tapped outlet. Trap may be readily suspended on piping itself.



Statement of the ownership, management, circulation, etc., required by the Act of Congress of March, 3, 1933, of
INSTRUMENTS, published monthly at Pittsburgh, Pa., for October 1st, 1934.

State of New York, County of New York, ss.:

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Richard Rimbach, who, having been duly sworn according to law, deposes and says that he is the publisher of INSTRUMENTS and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, embodied in section 411, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

Publisher, Richard Rimbach, 330 W. 42nd St., New York.
Editor, M. F. Behar, 330 W. 42nd St., New York.
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2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.) Instruments Publishing Company, Pittsburgh, Pa.; Jos. J. Vigneau, Pres., Pittsburgh, Pa.; Richard Rimbach, V. P. & Treas., New York, N. Y.

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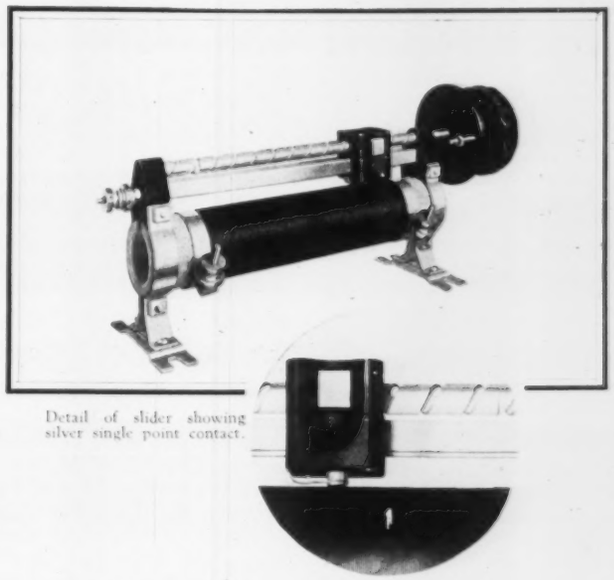

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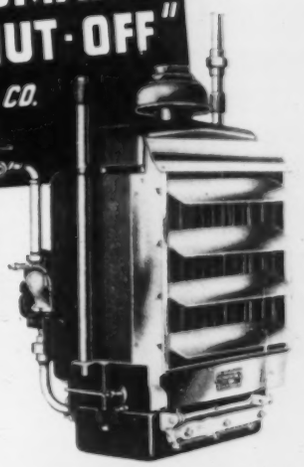

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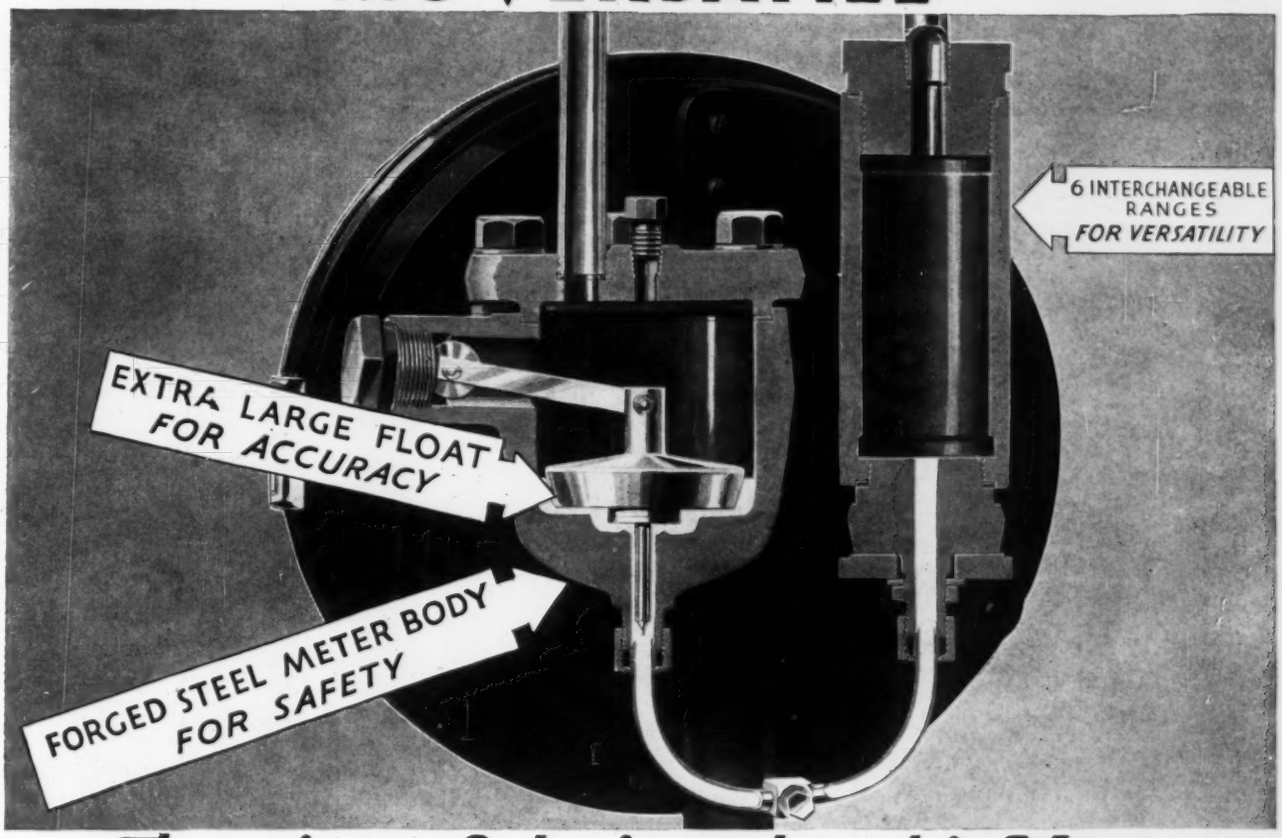

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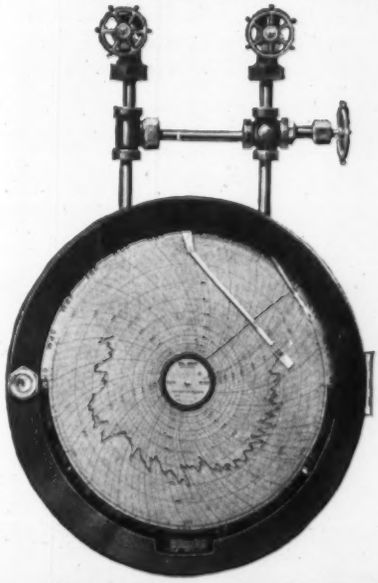

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